

Value of Distributed Energy Resources – E/EJ Value Informal Subgroup – Track 1 and 2 Report

This report presents findings of an informal stakeholder-led Environmental /Environmental Justice Value Subgroup (“E/EJ Value Subgroup” or “Subgroup”) formed as part of the Value of Distributed Energy Resources (“VDER”) proceeding.¹ Specifically it presents the work part of the Subgroup conducted regarding the environmental and public health value of avoided air pollution caused by distributed energy resource (“DER”) injections in New York State (“NYS”).

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I. Background

During the December 12, 2017, and the February 9, 2018, VDER Value Stack and Rate Design working group meetings, participants in the working groups discussed the need for preparatory and background work on environmental and environmental justice values of DER prior to the start of the Environmental Track, scheduled to begin in July. Department of Public Service Staff invited working group participants to form a subgroup to engage in this work and stated that although Staff would not lead the subgroup, Staff members would be interested in listening in on the subgroup's meetings.

In response to that discussion and suggestion by staff, a stakeholder-led E/EJ Value Subgroup was formed. The goal of this "unofficial" Subgroup is to gather necessary data and do any other background work to set the stage for an effective policy discussion on the "E" and "EJ" value in the Value Stack Working Group starting July 11th.

The initial E/EJ Value Subgroup had its first meeting on February 15, 2018 with all individuals and organizations that expressed interest in the Subgroup. The E/EJ Value Subgroup further invited all stakeholders to participate by providing notice in relevant dockets.³ The Subgroup held open monthly update calls to provide updates to all interested parties, including those who could not otherwise commit time or resources to the Subgroup. Between 10 and 60 people participated in these calls. For those individuals and organizations that could commit resources and time, the E/EJ Value Subgroup held working meetings approximately every two weeks. Given the number of tasks, the Subgroup further divided itself into four tracks, with the members of each track meeting as frequently as needed.

The E/EJ Value Subgroup consisted of the following Tracks:

Track 1 – Identifying the **amount of emission reductions** from DER injections. This Track worked on identifying the generation displaced by DERs, and gathering data on emission rates for CO₂, SO₂, NO_x, and PM.⁴

³ Institute for Policy Integrity at NYU School of Law, Pace Energy and Climate Center, Notice of VDER Phase 2 "E" and Environmental Justice Value Subworking Group (Feb. 28, 2018), <http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId={AE5F6F64-7E09-4998-802A-47660C91AE2E}>.

⁴ Members who initially signed up for Track 1 include Aaron Breidenbaugh; Luthin Associates; Janet Handal, Handal Associates; Melissa Kemp, Cypress Creek Renewables; Kolin Loveless, Bloom Energy; Chris Neidl, Brooklyn Solar Works; Nora Ostrovskaya, New York Metropolitan Transit Authority; Jeffrey Shrader, Institute for Policy Integrity at NYU Law; Joshi Sanjeevani, New York Power Authority; Emmett Smith, Azure Mountain Power; Geordi Taylor, Pace Energy and Climate Center; Burcin Unel, Institute for Policy Integrity at NYU Law; Sam Wilt, Natural Resources Defense Council; Avi Zevin, Institute for Policy Integrity at NYU Law.

Track 2 – Identifying the **value of avoided damages** from these emission reductions. This Track worked on using tools such as COBRA, BenMAP, and EASIUR to calculate NYS-specific values of avoided emissions.⁵

Track 3 – Identifying **policy options** to take into account Environmental Justice values. This Track worked on identifying values that cannot be captured by air quality improvements, and policy options for compensating DERs for such value other than ones with direct kWh links to direct investment incentives.⁶

Track 4 – Calculating **bill impacts** of findings. This Track worked on putting together rough calculations of bill impacts of paying DERs for E/EJ value based on the order-of-magnitude findings of Tracks 1,2, and 3.⁷

This document explains the work that has been done in **Tracks 1 and 2**, and summarizes the resulting “E” values that these Tracks were able to calculate given time and data constraints. Where possible, we suggest additional data work that can be done to get more accurate results.

II. Methodology

The methodology followed by Tracks 1 and 2 was based on the December 20 presentation by Policy Integrity and subsequent report on Valuing Emission Reductions from DERs.⁸ As explained in more detailed in the Policy Integrity report, attached as Appendix B, accurately calculating the “E” value of DERs requires five distinct steps:⁹

Step 1 determines what generation will be displaced by DERs.

Step 2 quantifies the emissions rates for displaced generators.

⁵ Members who initially signed up for Track 2 include Aaron Breidenbaugh; Luthin Associates; Miles Farmer, Natural Resources Defense Council; Rob Habermann, Pace Energy and Climate Center; Melissa Kemp, Cypress Creek Renewables; Jeffrey Shrader, Policy Integrity; Burcin Unel, Policy Integrity; Avi Zevin, Policy Integrity

⁶ Members who initially signed up for Track 3 include Aaron Breidenbaugh; Luthin Associates; Kartik Amarnath, New York City Environmental Justice Alliance; Adam Conway, Couch White – New York City; Adam Flint, Binghamton Regional Sustainability Coalition; Katrina Fritz, National Fuel Cell Research Center; Rob Habermann, Pace Energy and Climate Center; Sheryl Musgrove; Chris Neidl, Brooklyn Solar Works; Shiva Prakash, New York Lawyers for the Public Interest; Kelly Roache, Solstice; Devlyn Tedesco, Couch White – New York City; Sam Wilt, Natural Resources Defense Council.

⁷ Members who initially signed up for Track 4 include Aaron Breidenbaugh; Luthin Associates; Melissa Kemp, Cypress Creek Renewables; Kolin Loveless, Bloom Energy; Sheryl Musgrove; Geordi Taylor, Pace Energy and Climate Center.

⁸ Institute for Policy Integrity, Institute for Policy Integrity Presentation on Monetizing Externalities (Dec. 19, 2017), <http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId={39E7F5F8-5CD6-429E-AA22-BFAB9673F44A}>; JEFFREY SHRADER, BURCIN UNEL & AVI ZEVIN, INSTITUTE FOR POLICY INTEGRITY, VALUING POLLUTION REDUCTIONS: HOW TO MONETIZE GREENHOUSE GAS AND LOCAL AIR POLLUTION REDUCTIONS FROM DISTRIBUTED ENERGY RESOURCES (2018), http://policyintegrity.org/files/publications/Valuing_Pollution_Reductions.pdf [hereafter “DER Externality Report”]

⁹ DER Externality Report at 5.

Step 3 calculates the monetary value of the damages from emissions identified in Step 2.

Step 4 uses the emissions rates from Step 2 and damage estimate per unit of emissions from Step 3 to monetize the value of avoided emissions from displaced generation. Adjustments are needed if existing policies already put a price on emissions of some or all of the pollutants covered in Steps 1-3.

Step 5 to take into account any emissions produced by the DER itself is required for emitting DERs such as diesel generators or combined heat and power generators.

Tracks 1 and 2 of the E/EJ Value Subgroup worked on Steps 1 through 4 of this methodology to estimate the environmental damages that can be avoided as a result of kWh injections from non-emitting DERs. Below, we detail the work done by the Subgroup in each step.

A. Step 1: Identifying Displaced Generation¹⁰

Distributed energy resources produce environmental and public health benefits by displacing generation from emitting power generators. The first step in calculating this value, then, is to identify what generation will be displaced by DER injections.¹¹ If sufficient grid operation and market information is available, it is possible to identify, with a reasonable degree of precision, the specific generator or generators that would have operated in the absence of DERs. If such data are not available, there are techniques that can be used to approximate which generators were displaced by DERs.¹²

Subgroup Approach

The E/EJ Value Subgroup pursued several alternatives during their work.

First, various members of the Subgroup, at different times during the past months, have sought, but did not receive, high frequency information on the marginal generator or characteristics of the marginal generator from the New York Independent System Operator (“NYISO”). Information on the identity of the marginal generator for some historical period—e.g., 2016—would have allowed the Subgroup to make precise calculations of the value stack over that period to assess the likely effects of a policy to value DER injections in a locationally granular manner. However, because such data was not available, Track 1 of the E/EJ Value Subgroup worked to develop alternative methods to estimate seasonal hourly marginal generators.

Next, the Subgroup developed a methodology for estimating the probability that a generator is marginal, which would require data on only the generators that are getting paid at a given NYISO-interval, but not the identity of the marginal generator. But, again, we were not able to obtain the necessary data to do this estimation.

¹⁰ See generally DER Externality Report at 6-9.

¹¹ Even though this report focuses on injections, DERs that reduce behind-the-meter consumption also provide environmental benefits. In the current structure of the VDER proceeding, these benefits should be addressed in the rate design working group.

¹² DER Externality Report at 6-8 (describing methods for identifying or estimating marginal generators).

Instead, we have used published information on CO₂ marginal emission rate (“MER”) data to infer the fuel-type mixes of marginal generators and weights that can be used to scale the value of avoided emissions. Our calculations are explained in detail below.

Longer term options

Even though we think the results we present here are sufficient to give the Commission order-of-magnitude estimates, more accurate methods for calculating displaced generation caused by DER injections might be desirable as NYS works to achieve REV’s vision. Moving forward, there are three options available to the Commission.

- Working with NYISO to calculate MERs for local pollutants: While NYISO’s confidentiality concerns about identifying marginal generators are valid, the Commission, Staff and NYISO can work together to identify ways to publicly release information on MERs on pollutants other than CO₂ without identifying specific marginal generator information. For example, PJM releases this information at an aggregated peak/off-peak level.
- Working with NYISO to have NYISO directly calculate a more granular “E” value based on the damage values the Commission chooses, and release those values. Given that NYISO has the information on marginal generator(s) at a given time and location, this method can provide more accurate information, especially for locations where emission reductions produce the most environmental and public health value, such as New York City.
- Using regression estimates that are commonly used in economics literature to estimate zonal MERs for local pollutants.¹³

B. Step 2: Identifying Emission Rates of Displaced Generation¹⁴

Once the resources that are displaced by DERs have been identified, the next step is to determine the emissions rates of those displaced resources. These emissions rates are necessary to determine the benefits of avoiding emissions from each kWh of displaced emitting generation. The E/EJ Value Subgroup gathered different sources of information on air pollution emitted by electricity generators.

The Subgroup analyzed emission rates of four pollutants—fine particulate matter (“PM_{2.5}”), sulfur dioxide (“SO₂”), oxides of nitrogen (“NO_x”) and carbon dioxide (“CO₂”). These pollutants were analyzed because they are emitted by fossil fuel-fired power plants, have significant effects, and are included in available emission rate databases and damage modeling tools. Figure 1 shows emitting generators in the state.

Emission rates were identified using both historical emissions of existing generators and engineering estimates.

¹³ See DER Report at 18 (describing a methodology developed by Joshua Graff Zivin, Matthew Kotchen & Erin Mansur, in *Spatial and Temporal Heterogeneity of Marginal Emissions*, 107 J. Econ. Behavior & Org. 248 (2014)).

¹⁴ See DER Externality Report at 10-17.

Historical Emissions

Generators above a specific size threshold are required to directly measure and report the volume of emissions for some pollutants to state environmental agencies and/or the U.S. Environmental Protection Agency (“EPA”) Clean Air Markets Division (“CAMD”). Continuous emission monitors (“CEMs”) are used to measure and report NO_x, SO₂, and CO₂ emissions from generators that are subject to certain federal environmental program requirements.¹⁵ For pollutants where continuous emission measurement is not feasible or is particularly expensive (such as for PM), generators calculate and report emissions through monitoring of parameters that have a known relationship with emissions, such as operational characteristics of plant systems (temperature, pressure, liquid flow rate, pH), through periodic emissions testing, or based on quantities of fuel consumed and the technology used to generate electricity.¹⁶

Advantages. Short of real-time continuous measurements, historical measured emissions rates are generally the best measure of a particular generator’s emissions rate because they capture real-world factors and generator use. Therefore, they should be used when available. Historical emissions are verified by the EPA, are used for compliance with other environmental programs, and are publicly available (with some delay). If the values are based on actual emissions rather than engineering estimates (see limitations, below), they can provide a good indication of true emissions rates for generators that burn a variety of fuels.

Limitations. Large generators are required to submit emission data, but smaller generators can voluntarily supply the data. In the E/EJ Value Subgroup’s analysis, it appears that the majority of smaller generators in the NYISO-operated New York Control Area (“NYCA”) do supply data to the EPA, reducing the importance of this limitation. A more important limitation when applying EPA emissions data to generators in the NYCA comes from different reporting requirements for generators that burn different fuels. Non-coal-based fossil fuel generators can choose to install CEMs, but may also use verified engineering estimates of emissions based on operational characteristics. Almost none of the fossil-fuel powered generators in the NYCA burn coal, meaning that reported emissions data might still be based on engineering estimates. In addition, because it is difficult to directly measure certain pollutants such as PM, historical emissions rates for all pollutants may not be known for a given generator.

Finally, lack of temporal granularity may produce misleading emissions rate estimates. In particular, the use of yearly-average emissions rates may be problematic for generators that do not operate consistently over the course of a year, such as dual fuel peaking plants that may burn oil instead of natural gas when natural gas is unavailable or particularly expensive.

¹⁵ See 40 C.F.R. part 75.

¹⁶ See National Emission Standards for Hazardous Air Pollutants from Coal- and Oil-Fired Electric Utility Steam Generating Units, 77 Fed. Reg. 9,304, 9,370-72 (Feb. 16, 2012) (outlining compliance reporting options for the EPA Mercury and Air Toxics rule); *Stationary Source Emissions Monitoring*, U.S. ENVTL. PROT. AGENCY (last visited March 11, 2018), <https://www.epa.gov/air-emissions-monitoring-knowledge-base/basic-information-about-air-emissions-monitoring#stationary>.

Subgroup Experience. The E/EJ Value Subgroup used EPA’s eGrid and National Emissions Inventory (“NEI”) databases to calculate emissions rates for generators in the NYCA. The Subgroup was able to match records from the 2016 version of eGrid to 358 out of the 412 generators (87%) active in 2016 as reported in the 2016 NYISO “Gold Book”—a collection of load and capacity data for NYCA published annually by NYISO.¹⁷ The Subgroup calculated emissions rates for SO₂, CO₂, NO_x, and PM_{2.5} for these matched records.

For the remaining active generators, the Subgroup interpolated the emissions rates for SO₂, CO₂, and NO_x based on the primary and secondary fuels for each generator, as well as whether the generator was classified in the Gold Book as “dual fuel.” So, for instance, an unmatched dual fuel plant that primarily burned natural gas was estimated to have the average emissions rate of other dual fuel natural gas plants that were matched to eGrid.

The Subgroup calculated PM_{2.5} emissions rates based on data from the NEI. As discussed in the limitations section, above, particulate matter data is often based on engineering estimates due to the cost of real-time monitoring. In the Subgroup’s experience, the emissions rates for PM_{2.5} in the NEI were noisy. Some generators reported emissions rates 2 or even 3 orders of magnitude higher than other generators of a similar age, similar size, and that burned a similar fuel. Due to the noise in these data, the Subgroup trimmed outlying values. Any emissions rate larger than the 95th percentile of the emissions rate distribution was truncated to equal the 95th percentile.

One additional limitation with these databases is that emissions are reported for aggregated sets of plants at a single location. For instance, the NYCA generator list includes separate entries for each plant at the Danskammer Generating Station in Newburgh, NY. In eGrid, all of the plants at this location are assigned a single identifier and the aggregate emissions from all Danskammer plants are reported as one entry. Therefore, if emissions from individual plants—but not the whole generator—are avoided by DER, the plant-level emissions will either need to be inferred or the displaced generation will need to be calculated at the generator level.

Overall, the Subgroup found the eGrid and NEI databases to be easy to work with, and the data appeared to be sensible, aside from the particulate matter issues discussed above. The main challenges to using the data are (1) finding matches between the NYCA generator list and the EPA’s emissions databases; (2) aggregating or disaggregating emissions from individual plants or generators to match displaced generation; (3) the limited temporal granularity of the data; and (4) the failure of the data to specify emission rates when burning particular fuels for dual fuel generators.

Engineering Estimates

Engineering estimates of emissions rates are based on assumptions about known characteristics of generators. Accurate engineering estimates use considerations such as fuel type, heat rate of generating

¹⁷ NYISO 2016 Load & Capacity Data “Gold Book” at 38.

https://www.nyiso.com/public/webdocs/markets_operations/services/planning/Documents_and_Resources/Planning_Data_and_Reference_Docs/Data_and_Reference_Docs/2016_Load__Capacity_Data_Report.pdf

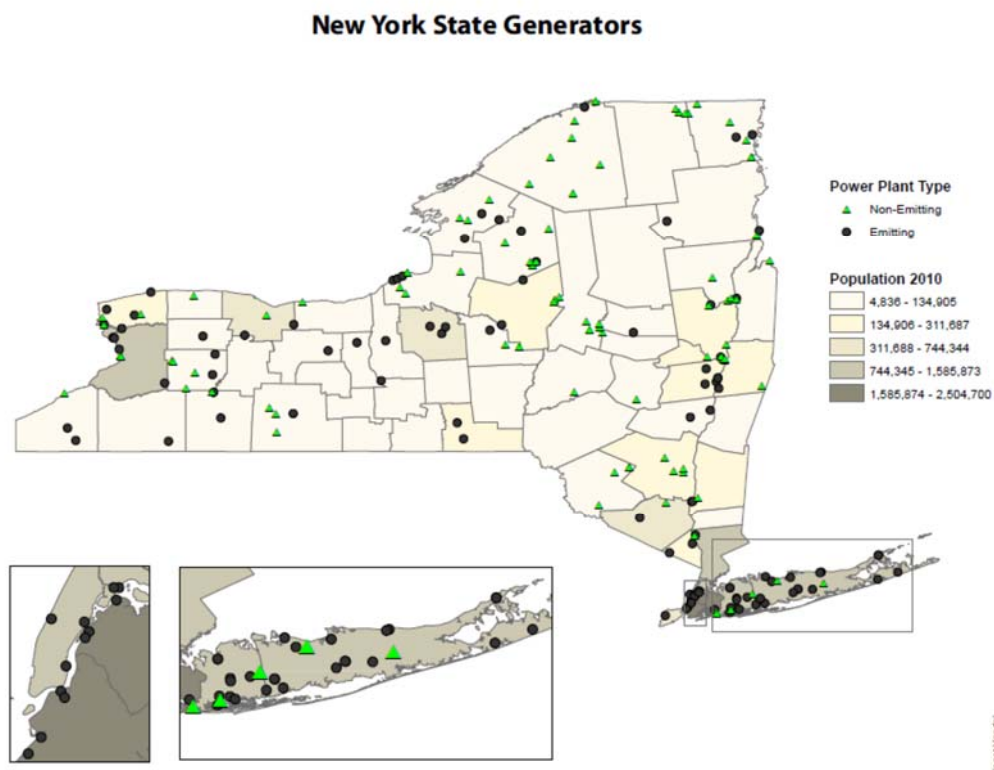
technology, emission control technology, and environmental and operational considerations to develop emissions rates that can be applied to generators with similar characteristics. Because of this, engineering estimates are sometimes referred to as “emission factors.”

Advantages. Where historical emissions rates are not available or lack sufficient granularity, engineering estimates can be used. Engineering estimates will be particularly valuable to assess emissions rates for polluting DERs like diesel generators. Such generators are too small to warrant CEMs.

Limitations. Engineering estimates are limited in their ability to capture real-world emissions rate variation due to changes in generator operational characteristics, equipment malfunction, or other unforeseen changes. Engineering estimates might also be unable to capture high frequency changes in emissions or emissions during phases when the generator is ramping up, running, and ramping down.

Subgroup Experience. The E/EJ Value Subgroup collected information on available engineering estimates, summarized in Table 2 of the attached Policy Integrity report and accompanying description.¹⁸ Aside from engineering estimates that were reported in eGrid and NEI data, the Subgroup did not directly work with other engineering estimates.

Figure 1: Emitting Generators in New York¹⁹



¹⁸ See DER Externality Report at 14-17.

¹⁹ All maps in this document are prepared by Janet Handal, Handal Associates.

C. Step 3: Calculating the Monetary Damages from Pollution Emissions

Air pollutants cause damage to human health, impair ecosystems, harm crops, and make it harder for workers to be productive. DERs provide value by avoiding emissions of these pollutants from fossil fuel-fired electricity generation, thereby avoiding these damages. The “E” value and an important component of the “EJ” value of DER injections, therefore, can be attributed to the value of environmental and health damage that would have occurred without those injections. Track 2 of the E/EJ Value Subgroup worked to investigate available methodologies that can be used to estimate the monetized damages that would be produced through emission of an additional unit of various air pollutants at specific times and in specific locations throughout New York. Using existing modeling tools, the E/EJ Value Subgroup developed estimated values of avoided emissions for four pollutants in each New York county. These dollar-per-ton damage estimates can be combined with the marginal ton-per-kilowatt-hour (kWh) emission rate estimates developed in Track 1 to arrive at dollar-per-kWh value estimates of DER injections in New York.

Damages Caused by Key Pollutants

Consistent with Track 1, the pollutants that Track 2 analyzed include three “local” pollutants—PM_{2.5}, SO₂, and NO_x—and one “global” pollutant—CO₂. The methodologies we have identified to value damages from a ton of local pollutants differs from the methodology identified to value damages from a ton of global pollutant.

Local pollutants produce damage by harming human health when inhaled and by directly affecting agricultural production.²⁰ PM, particularly PM smaller than 2.5 micrometers (PM_{2.5}), causes serious harm to human health, including death, by affecting hearts and lungs. SO₂ exacerbates asthma, contributes to acid rain, and breaks down into PM_{2.5}. NO_x causes damage by breaking down into PM_{2.5} and by creating asthma-causing ozone pollution (smog) when combined with other pollutants in the presence of sunlight. A number of geographic-specific factors influence the total damage caused by a ton of local pollutant emissions including air transport; the preexisting ambient concentration of the pollutant; population density; and the prevalence of health conditions and other social factors, which make individuals more vulnerable to additional pollution.²¹ Therefore, the monetized damages of a ton of emissions of a local pollutant depends significantly on *where* the pollutant is emitted. Because ozone is formed when NO_x and other pollutants are exposed to sunlight, the timing of emissions of local pollutants —daytime and nighttime—also matters.²² The methodologies we have identified for valuing avoided local pollution take into account the location and time of emissions.

Global pollutants—specifically CO₂—produces damage by mixing in the atmosphere and changing the climate, which results in health, property, agricultural, and social harms.²³ The damage caused by a ton of CO₂ emissions, however, is independent of where and when that ton is emitted. The methodology

²⁰ See DER Externality Report at 19-20.

²¹ DER Externality Report at 20-21.

²² DER Externality Report at 20.

²³ See DER Externality Report at 20.

we have identified for valuing avoiding CO₂ emissions, therefore, does not depend on the location or time of emissions.

Assessing Damages from Local Pollutants

Because the level of damage caused by local pollutants depends on a variety of locational and temporal factors, obtaining accurate estimates requires the use of modeling tools that take into account these factors. As was discussed in Policy Integrity’s December 20 presentation and attached report, there are several potential tools that the Commission could use to estimate location-specific damages of an additional ton of pollution, with varying degrees of complexity.²⁴

These tools would all allow the Commission to obtain an estimate of the damage associated with an additional ton of the primary local air pollutants emitted by fossil fuel-fired power plants. The Commission’s decision to select among these tools may be driven by a general tradeoff between the granularity of the data produced and the extent to which additional data is required. The most granular methods use high-resolution population data with time-varying pollution transport models. Less granular methods make stronger assumptions or use more aggregated data to reduce the complexity of calculation. Selecting the most granular method possible will provide the Commission with the most accurate information on the health benefits of DER injections. Granular modeling is particularly important for estimating how DER can affect environmental justice concerns related to disparate health impacts of air pollution, since these effects generally manifest themselves at the neighborhood level. However, because development of granular New York-specific modeling can be time and labor intensive, less granular tools may be appropriate in the near-term and are available to be used now.

We first present two “plug and play” models that the Subgroup used to determine marginal damage estimates for emissions from each county in New York. We then describe three more complex and granular models that could be used in the longer-term to develop more precise estimates of marginal damages.

Tools that Can be Used in the Near Term

Given the limited time the Subgroup had, we started with two plug-and-play tools that can be used to develop damage estimates of an additional ton of an air pollutant and that do not require substantial additional data requirements: COBRA and EASIUR. While these two models have different tradeoffs, either could be used in the near-term as part of the methodology to calculate “E” values. In this report, we present estimates of the value of DER injections using both of these models.

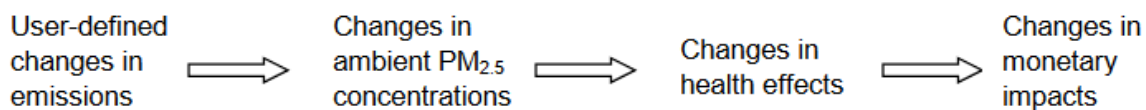
COBRA. The Co-Benefits Risk Assessment (COBRA) tool has been developed by the EPA for use by state and local governments to estimate the economic and health damages associated with air pollution changes.²⁵ Users supply changes in NO_x, SO₂, and PM_{2.5} emissions caused by a policy, and COBRA walks

²⁴ See generally DER Externality Report at 22-24.

²⁵ See generally U.S. Env’tl. Prot. Agency, User’s Manual for the Co-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA) (3rd ed. 2017), https://www.epa.gov/sites/production/files/2017-10/documents/cobra_user_manual_septem-ber2017_508_v2.pdf.

through a number of steps to estimate and monetize county-level damages caused by secondary PM_{2.5} formed by the breakdown of those pollutants.

Figure 2: COBRA Steps for Calculating Pollution Damages²⁶



COBRA uses a relatively simple built-in air pollution transport model. COBRA damages are based on mortality, and morbidity due to nonfatal heart attacks and cardiovascular illness. COBRA presents two sets of damage estimates: “high” estimates based on the top of the range of effects of pollution at each step as provided in the academic literature, and “low” estimates based on the bottom of the range of effects in the academic literature.

Necessary Data. COBRA is a true plug-and-play tool. It has a simple point-and-click interface in which the user can specify a change in emissions of a particular pollutant in a particular county and it will provide monetized estimates of health damages and economic losses associated with that change in pollution. COBRA can also be modified with custom population, baseline health, and baseline emission data as well as custom damage functions.

Advantages. The primary benefit of COBRA is its ease of use. No additional data is required and the point-and-click interface means that damage estimates can be obtained without any coding. In addition, COBRA has been used previously by the Commission to estimate the health impacts of avoided NO_x and SO₂ emissions in its benefit cost analysis for the Reforming Energy Vision proceeding.²⁷

Limitations. COBRA uses relatively simple air pollution modeling and operates only as granularly as the county level. It therefore cannot accurately estimate neighborhood level damages that would be necessary for teasing out disparate impacts among neighborhoods or capture high damages that results in certain conditions such as very high temperature days. In addition, COBRA estimates damages solely based on exposure to PM_{2.5}—formed directly and through the breakdown of NO_x and SO₂. Therefore, it does not include direct health and agricultural impacts from NO_x and SO₂ or health impacts associated with ozone.

Subgroup Experience. Because of its ease of use, the E/EJ Value Subgroup has been able to use COBRA to produce marginal damage estimates for counties across New York State. Track 2 members spent approximately 30 hours running the COBRA model assuming a single ton increase of each local pollutant (PM, NO_x, SO₂) for each county in New York State. This produced a table of values—both “high” and

²⁶ *Id.* at 5.

²⁷ See New York Department of Public Service, Docket No. 14-M-0101, *Staff White Paper on Benefit-Cost Analysis in the Reforming Energy Vision Proceeding* at C-2 to C-4 (2015), [https://www3.dps.ny.gov/W/PSCWeb.nsf/96f0fec0b45a3c6485257688006a701a/c12c0a18f55877e785257e6f005d533e/\\$FILE/Staff_BCA_Whitepaper_Final.pdf](https://www3.dps.ny.gov/W/PSCWeb.nsf/96f0fec0b45a3c6485257688006a701a/c12c0a18f55877e785257e6f005d533e/$FILE/Staff_BCA_Whitepaper_Final.pdf).

“low” estimates—of the marginal damages that can be combined with emissions rate information developed in Track 1 to arrive at \$/kWh damage rate estimates that are presented below.

EASIUR. Estimating Air Pollution Social Impact Using Regression (EASIUR) is a model of the damages from emission of primary PM_{2.5}, SO₂, NO_x, and NH₃.²⁸ EASIUR was created by academics at Carnegie Mellon University and is publicly available. EASIUR uses regression analysis of high-resolution, detailed pollution transport model output from the Comprehensive Air Quality Model with Extensions (CAMx) to derive simple estimates of pollution transport on a 36 by 36-kilometer grid for the United States. EASIUR provides estimates of damages for four seasons and at three different stack heights—ground level, 150m, and 300m.

Necessary Data. EASIUR does not require any additional data beyond the geographic location of the pollution source and the season of emission. EASIUR is available using a simple online website that will provide marginal monetized damage estimates for a given address or set of latitude/longitude coordinates or can be used more systematically with spreadsheets or GIS shapefiles that identify pollution sources.²⁹ EASIUR allows modifications to the value of statistical life, and concentration-response functions.

Advantages. As compared to COBRA, the primary advantage of EASIUR is the use of more accurate modeling of pollution transport. EASIUR provides more accurate estimates of air pollution damage based on the location of emissions without the cost of complex and time-consuming modeling of detailed pollution transport. EASIUR's 36 km x 36 km locational granularity may also be somewhat more accurate than county-level damage estimates produced by COBRA.

Limitations. As with COBRA, the damage estimates produced by EASIUR are based on mortality due to secondary PM and do not include health or environmental damages caused by exposure to NO_x, SO₂, and ozone. Unlike COBRA, EASIUR does not provide an easy way to modify underlying assumptions such as population size, baseline health, or baseline emission data. It also does not appear to be updated as often as COBRA.

Subgroup Experience. As part of the Subgroup process, we have used EASIUR to identify marginal damage estimates specific to each generator in New York State for each local air pollutant. We entered the latitude and longitude of each generator into EASIUR to obtain seasonal generator-specific marginal damage estimates for PM_{2.5}, NO_x, and SO₂ that are then combined with emissions rates developed in Track 1 to arrive at \$/MWh damage rate estimates that are presented below.

Longer-term Modeling Tools

The tools above would allow the Commission to develop and implement estimates of avoided local pollutant damages due to DER quickly, with minimal additional data and staff commitment. However, other tools that allow more granular damage estimates and that incorporate additional types of

²⁸ Jinhyok Heo, Peter J. Adams & H. Oliver Gao, Public Health Costs of Primary PM_{2.5} and Inorganic PM_{2.5} Precursor Emissions in the United States, 50 Env'tl. Sci. & Tech. 6061 (2016).

²⁹ Available at <https://barney.ce.cmu.edu/~jinhyok/easiur/>.

damages associated with air emissions may be more appropriate for use over the longer term. These include an EPA tool, BenMAP, the construction of custom modeling, and a new reduced form model called InMAP.

While we have identified these options, unlike the work done to develop New York-specific damage estimates using COBRA and EASIUR, the E/EJ Value Subgroup has not attempted to develop specific damage estimates using these tools. Notably, because of the availability of COBRA and EASIUR, the adaptation of more granular tools to New York's electricity market need not slow adoption of an "E" value methodology that includes local pollutants.

BenMAP. BenMAP is a tool created by the EPA to calculate and map damages from ozone and PM_{2.5} in the United States.³⁰ BenMAP does not include pollution transport modeling. Users specify the change in ambient concentration of pollution that they expect will occur due to a policy, and BenMAP monetizes the health impacts of that change using high-resolution population data (a 12 by 12-kilometer grid).

Necessary Data. BenMAP includes data on the relationship between changes in ambient concentration of PM_{2.5}, NO_x, and SO₂ and health impacts, and monetizes those impacts using population density and pollution damage functions derived from academic publications. BenMAP requires data on the location and season of emissions and the addition of air transport modeling. It can also use user-defined population data, baseline health data, and pollution damage functions to extent the Commission has better data on these factors than is included in the standard BenMAP package.

Advantages. As compared to the near-term tools described above, BenMAP has two primary benefits. First, it allows more granular analysis that would facilitate neighborhood level damage estimates that are useful for appropriately valuing environmental justice benefits of DER injections. Second, BenMAP includes damage estimates and monetization of health impacts related to ozone in addition to PM_{2.5}. As compared to custom modeling (described below), BenMAP is beneficial because it requires much less data and expert judgment related to the relationship between changes in pollution concentration, expected health effects, and monetization of those effects.

Disadvantages. The primary limitation for BenMAP is that it does not include any air transport modeling. Because pollutants can settle far from where they are initially emitted, this can be a substantial limitation. The Commission would therefore need to create or commission air transport modeling specific to New York using tools such as CAMx.

Custom Modeling. The most granular and detailed option would be for the New York PSC—either directly or through a third party—to build a custom model that takes into account as many factors affecting damage per unit of emissions as possible. A recent example of such an approach is the Bay

³⁰ See generally U.S. Env'tl. Prot. Agency, Environmental Benefits Mapping and Analysis Program – Community Edition: User's Manual (2017), https://www.epa.gov/sites/production/files/2015-04/documents/benmap-ce_user_manual_march_2015.pdf.

Area Clean Air Plan³¹. The Bay Area Air Quality Management District (“BAAQMD”) created a custom tool that translates emissions of multiple different pollutants into changes in pollution concentration throughout the Bay Area.³² The tool uses weather data to understand how pollutants are transported around the Bay Area, and it uses complex atmospheric chemistry models to understand how different primary pollutants cause secondary pollutants in the region. For instance, ozone is created by a complex interaction between different pollutants and sunlight, so the atmospheric chemistry models are important to understanding how ozone pollution can be addressed.

The model then uses population density to translate pollution concentration changes into human exposure. The exposure determines health effects according to the pollutant being considered and the health conditions of the exposed population. The BAAQMD focuses on PM, ozone, and greenhouse gas pollution, but in principle, any pollutants could be incorporated into a similar methodology.

Necessary Data. Unlike the approaches described above, building a custom model requires substantial data related to population density, population health characteristics, local economic characteristics, and ambient air quality characteristics. It also requires expert judgment to choose appropriate parameters related to air transport modeling, the health effects of given ambient pollution concentrations, and the monetization of expected health effects.

Advantages. The primary benefits of a custom method are the ability to model damages at a neighborhood level and the ability to incorporate variation in population density and population health. This ability is especially important for states like New York, which have significant disparities in population density and preexisting population health characteristics. Pollutants emitted in areas near big urban cities would cause substantially higher exposure than the same pollutant emitted in more sparsely populated rural regions.

Limitations. The primary limitation in using a custom model is the need to construct it and the time and data resources required to do so.

InMAP. Intervention Model for Air Pollution (InMAP) is another, newly developed, reduced complexity air model that estimates air pollution health impacts of reduced pollution.³³ InMAP is created by academics at University of Washington and University of Minnesota, and is publicly available.³⁴ It is designed to reduce computation costs relative to chemical transport models, yet it allows for more spatially detailed results than are available with existing reduced-complexity models such as EASIUR by introducing a variable-resolution grid that focuses on human exposures by employing higher spatial

³¹ See generally Bay Area Air Quality Mgmt. District, *Spare the Air Cool the Climate: Final 2017 Clean Air Plan* (2017), <http://www.baaqmd.gov/~media/files/planning-and-research/plans/2017-clean-air-plan/attachment-a-proposed-final-cap-vol-1-pdf.pdf?la=en>.

³² See David Fairley & David Burch, Bay Area Air Quality Management District, *Multi-Pollutant Evaluation Method Technical Document: 2016 Update* (2016), http://www.baaqmd.gov/~media/files/planning-and-research/plans/2017-clean-air-plan/mpem_nov_dec_2016-pdf.pdf.

³³ Christopher W. Tessum, Jason D. Hill & Julian D. Marshall, *InMAP: A Model for Air Pollution Interventions*, PLOS One, April 19, 2017, <https://doi.org/10.1371/journal.pone.0176131>.

³⁴ Available at <http://spatialmodel.com/inmap/>.

resolution in urban areas and lower spatial resolution in rural and remote locations and at high altitude. It is amenable to running many scenarios and theoretically simple enough for use by non-experts.

Necessary Data. InMAP is designed for ease of use. The only input required for InMAP is a set of shapefiles containing locations of changes in annual total emissions of VOCs, SO₂, NO_x, NH₃, and primary fine particulate matter (PM_{2.5}).

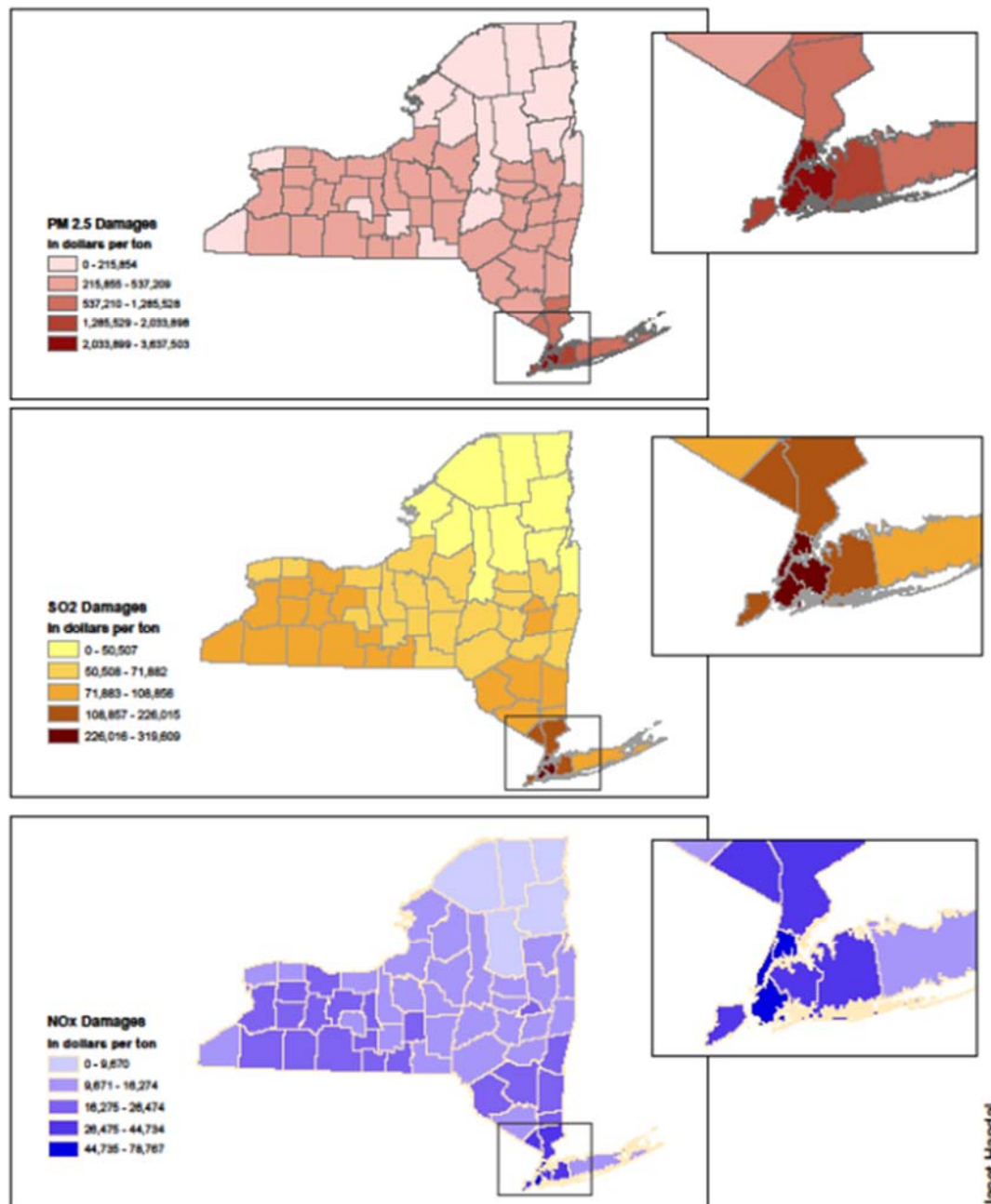
Advantages. As compared to COBRA, the primary advantage of InMAP is the use of more accurate modeling of pollution transport. It uses a variable-resolution computational grid, which allows the model to save time by focusing computational resources in areas where extra spatial detail is most useful. This feature of InMAP allows it to calculate how different demographic groups are exposed to PM_{2.5} even when these demographic groups live in adjacent neighborhoods. Therefore, InMAP can be particularly valuable for evaluating the environmental justice benefits of DER injections related to air quality changes.

Limitations. As with COBRA and EASIUR, the damage estimates produced by InMAP are based on mortality due to secondary PM and do not include health or environmental damages caused by exposure to NO_x, SO₂, and ozone. And, similar to EASIUR, it does not provide an easy way to modify underlying assumptions such as population size, baseline health, or baseline emission data.

Track 2 Sample Local Pollutant Damage Estimates

Sample damage estimates from the COBRA model are shown in the maps in Figure 3. The figure shows estimates of the dollar value of health effects from one ton of emissions in the high damage scenario built into COBRA. One can see that damages per ton of all three of the pollutants is highest in the downstate area around New York City because of the larger exposed population. Damages per ton are highest for primary PM_{2.5}, making reductions in the emission of this pollutant particularly valuable.

Figure 3: COBRA Estimated Damages for Emissions PM_{2.5}, SO₂ and NO_x (\$/ton)



Assessing Damages from Global Pollutants

Damages from greenhouse gases do not depend on the time or location of release, making the calculation of their damage per unit of emissions particularly straightforward. The U.S. government Interagency Working Group's (IWG) Social Cost of Carbon is the best estimate of the damages caused by

greenhouse gas emissions.³⁵ It is, therefore, the best tool for the Commission to adopt to value the avoided greenhouse gas emissions caused by DER injections as the Commission is already doing. While there is less variety in available values for climate damages, the Commission can choose among a number of discount rates included in the IWG Social Cost of Carbon documentation that best fits its policy preferences.

Overview of the Social Cost of Carbon

The Social Cost of Carbon is the net-present value of damage caused by the emission of one metric ton of carbon dioxide today. The IWG first developed the Social Cost of Carbon in 2010 and updated the estimate in 2013 and 2015.³⁶ The Social Cost of Carbon was developed through an academically rigorous, regularly-updated, and peer-reviewed process. The Social Cost of Carbon values were developed by averaging the three most widely cited climate economic impact models that link physical impacts to the economic damages of carbon dioxide emissions.

The IWG’s estimate has been repeatedly endorsed by government reviewers, courts, and experts. In 2014, the U.S. Government Accountability Office reviewed the IWG’s methodology and concluded that it had followed a “consensus-based” approach, relied on peer-reviewed academic literature, disclosed relevant limitations, and adequately planned to incorporate new information through public comments and updated research.³⁷ In 2016, the U.S. Court of Appeals for the Seventh Circuit held that relying on the IWG’s estimate was reasonable.³⁸ The National Academy of Sciences completed a robust review of the Social Cost of Carbon calculation in 2017, lending additional credibility to the metric and endorsing several changes that would likely lead to a higher Social Cost of Carbon estimate.³⁹ And though the current Administration recently withdrew the IWG’s technical support documents, experts continue to recommend that agencies rely on the IWG’s Social Cost of Carbon estimate as the best estimate for the external cost of greenhouse gases.⁴⁰

Selecting the Appropriate Social Cost of Carbon Value

The federal Social Cost of Carbon estimates are not a single number, but instead a range of four estimates, based on three discount rates, plus a 95th percentile estimate that represents catastrophic, low-probability outcomes.⁴¹ Three of the options include estimates using an average (rather than worse-than expected) damage estimate of three climate-economic models under three different discount rates—5 percent, 3 percent, and 2.5 percent. Discount rates allow economists to measure the value of money over time—the tradeoff between what a dollar is worth today and what a dollar would be worth

³⁵ See DER Report at 24-25 and accompanying notes.

³⁶ See Iliana Paul, Peter Howard & Jason A. Schwartz, *The Social Cost of Greenhouse Gases and State Policy: A Frequently Asked Questions Guide* 13-15(2017), http://policyintegrity.org/files/publications/SCC_State_Guidance.pdf [hereinafter “SCC FAQ”].

³⁷ SCC FAQ at 14.

³⁸ *Zero Zone v. U.S. Dep’t of Energy*, 832 F.3d 654 (2016).

³⁹ NATIONAL ACADEMIES OF SCIENCES, ENGINEERING AND MEDICINE, *Valuing Climate Damages: Updating Estimation of the Social Cost of Carbon Dioxide*, National Academies Press (January 2017), <https://www.nap.edu/catalog/24651/valuing-climate-damages-updating-estimation-of-the-social-cost-of>.

⁴⁰ Richard L. Revesz et al., *Global Warming: Improve Economic Models of Climate Change*, 508 *Nature* 173 (2014).

⁴¹ SCC FAQ at 24-25.

in the future. Higher discount rates result in a lower Social Cost of Carbon, as compared to lower discount rates. The fourth option is taken from the 95th percentile of the Social Cost of Carbon estimates using a 3-percent discount rate. The monetized value of damages for each option increases over time so that 2020 marginal damage values are higher than 2018 marginal damage values.

The Commission can choose among these four methodological options, and as is outlined below, different states have adopted each option in various proceedings. Each option represents a policy choice that the Commission could adopt.

- The 3-percent discount rate, average damage estimate represents the “central estimate.”⁴² This estimate is most widely used for regulatory policies.
- The 2.5-percent discount rate was included by the IWG as a constant-rate approximation of a declining discount rate.⁴³ Since the IWG undertook its initial analysis, a consensus has emerged among leading climate economists that a declining discount rate should be used for climate damages to reflect long-term uncertainty in interest rates.
- The fourth value is taken from the 95th percentile of the Social Cost of Carbon in all models with the 3-percent discount rate, which represents the expected damages from catastrophic, low-probability consequences of climate change.⁴⁴
- While the 5 percent discount rate was included in the IWG analysis, the Commission should consider the central estimate as a lower bound.⁴⁵ A number of types of damage from climate change are missing or poorly quantified in the Social Cost of Carbon estimates and the 2017 National Academy of Sciences report supported using a declining discount rate to account for uncertainty associated with climate damages.

Use of the Social Cost of Carbon in New York State

The Commission has endorsed the use of the Social Cost of Carbon as a tool to monetize the impacts of greenhouse gas emissions and the Interagency Work Group estimates as appropriate values. The Commission adopted the Social Cost of Carbon 3-percent central estimate as the best tool to monetize marginal climate damage costs in its benefit-cost analysis of resource portfolios as part of the Reforming Energy Vision proceeding.⁴⁶ The Commission also used the Social Cost of Carbon “central” 3-percent discount rate estimate as the basis for valuing the avoided climate damages provided by existing nuclear plants when establishing payment rate for Zero Emissions Credits in the Clean Energy Standard order.⁴⁷ Therefore, the E/EJ Value Subgroup used the central value, converted to nominal dollars in this work.

⁴² SCC FAQ at 17.

⁴³ SCC FAQ at 19.

⁴⁴ SCC FAQ at 25.

⁴⁵ SCC FAQ at 19.

⁴⁶ N.Y. Pub. Serv. Comms’n, Case No. 14-M-001, *Order Establishing the Benefit Cost Analysis Framework* at 17-18, 27 (2016), <http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7Bf8C835E1-EDB5-47FF-BD78-73EB5B3B177A%7D>.

⁴⁷ N.Y. Pub. Serv. Comms’n, Case No. 15-E-0302, 16-E-0270, *Order Adopting a Clean Energy Standard* at 133-35 (2016), <http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7B44C5D5B8-14C3-4F32-8399-F5487D6D8FE8%7D>.

D. Step 4: Calculating the Monetary Value of the Avoided Externality from Displaced Generation

Once the displaced resource has been identified and both the emissions rates and the damage per unit of emissions are known, these two values can be multiplied to get the monetary value of avoided, external damages per unit of bulk-system generation that is displaced by a non-emitting DER.⁴⁸ If the generator that was displaced is not subject to another price on emissions of PM_{2.5}, SO₂, NO_x, or CO₂, then this value represents the externality avoided by a non-emitting DER. If other policies that internalize the damage associated with emission of these pollutants exist, then such policies need to be taken into account.

Calculating the Value of the Avoided Externality When No Additional Policies Price Emissions

For a given pollutant, if there is no other policy to price emissions from power generators, then the per-kWh environmental value of DER is simply the emissions rate of the displaced generator multiplied by the damage per unit of generation. For instance, consider a marginal generator emitting PM_{2.5}. Assume that the generator produces 0.00005 metric tons of PM_{2.5} per MWh of generation. Further, assume that each ton of PM_{2.5} causes \$500,000 in external damage from mortality, lost health, and other factors. If no other federal or state policy causes the generator to internalize the damage caused by these emissions, then the value of avoiding emissions from this generator is $0.00005 \times 500,000 = \25 per MWh, or 2.5 cents per kWh.

Calculating the Value of the Avoided Externality in the Presence of Additional Emission Price Policies

If other policies do price emissions for the pollutant, then this price should be taken into account when calculating the external damage. Additionally, if NYISO ends up implementing carbon pricing, the value of avoided CO₂ emissions should be adjusted accordingly.

Consider the case where displaced generation comes from a NY generator larger than 25 MWs. Such a generator would be required to hold RGGI permits for its emissions. These permits are current around \$4 per metric ton of CO₂, while the damage per ton of CO₂, as given by the Social Cost of Carbon, is around \$50 in nominal terms. Therefore, for this generator, the uninternalized value of CO₂ emissions is $\$50 - \$4 = \$46$. If the generator emits 0.5 metric tons of CO₂ per MWh of generation, then the value of avoiding those emissions is $46 \times 0.5 = 23$ dollars per MWh, or 2.3 cents per kWh.

III. The Subgroup's Calculation of the Value Stack for PM_{2.5}, SO₂, NO_x, and CO₂

The E/EJ Value Subgroup used the information it gathered on marginal emissions rates of CO₂, emissions rates of other pollutants, and damages to calculate example value stacks for four pollutants from non-emitting DERs: PM_{2.5}, SO₂, NO_x, and CO₂. It is important to note once again that this work was not intended to calculate “the” value stack for avoiding these four pollutants, but rather to give order-of-magnitude estimates that can inform policy discussions and show how these values change by hour, zone, and season.

⁴⁸ See DER Externality Report at 26-27.

This section describes the Subgroups methodology and summarizes the values.

A. Marginal Generation

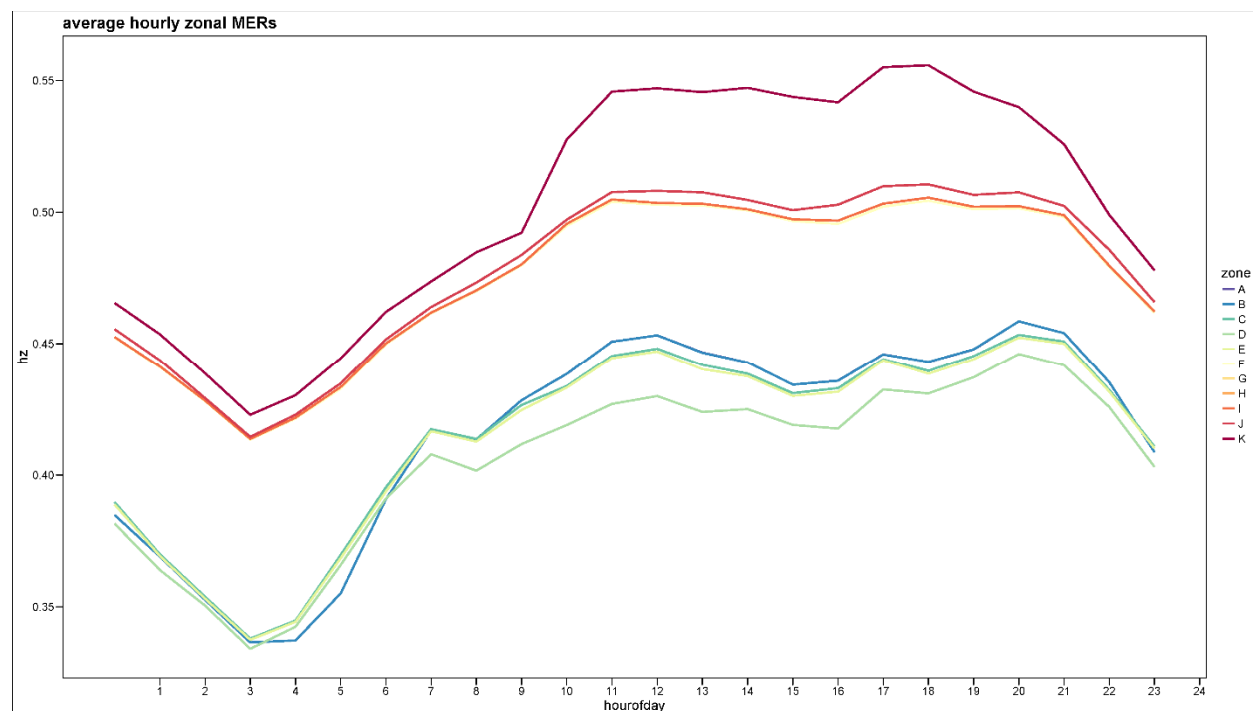
As we discussed above, the E/EJ Value Subgroup was not able to obtain information from NYISO on marginal generators. However, NYISO has released two sources of data that allowed the Subgroup to calculate rough estimates of the “E” value: zonal, quarterly marginal fuel from the Gold Book and zonal, hourly CO₂ marginal emission rates for 2015 and 2016.⁴⁹ The Subgroup initially calculated a quarterly “E” value using Gold Book marginal fuel information. Feedback from E/EJ Value Subgroup members and other parties indicated interest in higher-frequency estimates of the “E” value to assess whether dispatchable DERs could receive higher values for short periods of time such peak periods when especially high-emitting generators are on the margin.

Given this feedback, the Subgroup developed a method, outlined below, for translating hourly CO₂ MERs into a more holistic “E” value, including both CO₂ and local pollutants. For the CO₂ component of the “E” value, we multiplied the MERs by SCC-RGGI as we described above. For other local pollutants, we relied on CO₂ MERs to infer information about the type of the marginal generators. Even though the MERs released by NYISO are for only CO₂, they still provide some information on potential characteristics of the marginal generator. Therefore, we used the CO₂ MER data to infer the fuel-type mixes of marginal generators and to generate weights that can be used to scale the value of avoided local pollutant emissions. This method has the primary limitation that it cannot distinguish between marginal generation by different generators of the same fuel type in a given zone, but it has the advantage of providing high-frequency, publicly replicable estimates.

Figure 4 shows average hourly zonal marginal CO₂ emissions rates based on the NYISO data that covers 2015 and 2016. As can be seen from the figure, MERs vary significantly between different zones and different hours. In other words, marginal generators, and hence the “E” value of DERs, vary with time and location.

⁴⁹ Sam Newell et al., The Brattle Group, Calculation of Hourly MERs for 2017 Customer Cost Impact Analysis (Mar. 7, 2018), https://www.nyiso.com/public/webdocs/markets_operations/committees/bic_miwg_ipptf/meeting_materials/2018-03-19/Calculation%20of%20Hourly%20MERs%20for%202017%20Customer%20Cost%20Impact%20Analysis%2020180308%20FOR%20POSTING.pdf.

Figure 4: Average Hourly Zonal Marginal CO₂ Emission Rates



Based on the data available in eGrid, we know that natural gas generators produce around 0.52 metric tons of CO₂ per MWh, oil and coal generators produce about 1.1 metric tons, and zero emitting generators—by definition—produce no CO₂ (see Table 1 below). If the marginal emission rate in a given hour and zone is less than 0.52, for example like most upstate zones, then one can infer that zero-emitting generation was on the margin for at least part of that hour. Likewise, if the marginal emission rate in a given hour is above 0.52, like most downstate zones between 9 a.m. and 10 p.m., then one can infer that some oil or coal was on the margin during that hour.

According to the NYISO Gold Book, natural gas is the most common marginal fuel.⁵⁰ Therefore, the E/EJ Value Subgroup assumed that some natural gas was on the margin for all hours in which the marginal emission rate of CO₂ was not exactly zero. The Subgroup then inferred how much zero-emitting or higher-emitting fuel was on the margin based on how far the emission rate deviated from the average emissions rate for natural gas generators in the state (0.52 tons per MWh (see Table 1 below)).

⁵⁰ Gold Book 2016 Figure A-8.

In particular, the Subgroup used the following formulas to calculate the values of the local pollutants stack based on hourly, zonal marginal emission rates of CO₂ as published by the NYISO:

$$V_{pit} = \begin{cases} \frac{MER_{it}^{CO_2}}{0.52} V_{pit}^{gas} & \text{if } MER_{it}^{CO_2} \leq 0.52 \\ \left(\frac{1.1 - MER_{it}^{CO_2}}{1.1 - 0.52} \right) V_{pit}^{gas} + \left(\frac{MER_{it}^{CO_2} - 0.52}{1.1 - 0.52} \right) V_{pit}^{oil} & \text{if } MER_{it}^{CO_2} > 0.52 \end{cases}$$

Where V_{pit} is the value of avoided external damages from emissions of local pollutant p in zone i in hour t , $MER_{it}^{CO_2}$ is the marginal emission rate of CO₂ in zone i in hour t , V_{pit}^{gas} is the generation-weighted average value of avoided external damages per unit of generation from natural gas power plants emitting pollutant p in zone i in hour t , and V_{pit}^{oil} is the same value for oil generation. The value of 1.1 is the highest emissions rate of CO₂ recorded in the MERs published by NYISO.⁵¹ If a zone does not have oil generators, then it is assumed that the generation comes from other zones and has the same value as the average oil generation in the state.⁵²

To understand the intuition behind this equation, consider a series of cases. First, if the marginal emission rate of CO₂ is 0, then the generation in that hour came entirely from zero-emitting resources. Then, the top line of the equation will be equal to zero, because $\frac{0}{0.52} = 0$. In other words, a kWh of electricity injected by a DER would displace a non-emitting resource, and would not bring any incremental environmental benefits due to avoided local pollutant emissions.

If the CO₂ MER is exactly equal to the average emissions rate for natural gas of 0.52, then the top equation will calculate the value for the given pollutant as being exactly equal to the natural gas value because $\frac{0.52}{0.52} = 1$. In other words, a kWh of DER injection would displace generation from a typical natural gas plant in that zone, and therefore bring an environmental value based on the emissions rates of such a plant.

If the marginal emission rate for CO₂ is above 0.52, then the bottom line of the equation applies. First, consider a marginal emission rate for CO₂ that is very close to the average rate for natural gas generators. In that case, the value for V_{pit} will be very close to V_{pit}^{gas} because the first term is $\frac{1.1-0.52}{1.1-0.52} = 1$ while the second term is $\frac{0.52-0.52}{1.1-0.52} = 0$. Therefore, both the global and local pollutant environmental benefits of a DER injection would be closer to the benefits of avoiding natural gas generation.

⁵¹ Technically, higher values are recorded for a few hours in Zone K. It is unclear that these recordings are accurate, however, so we truncate those observations to be equal to the maximum value of 1.1 recorded in the other zones.

⁵² This final assumption is made for convenience. We assume that high-emitting imports are likely coal fired. For some pollutants like CO₂, the emissions rate is similar across the two fuels. For other pollutants, the emissions rate varies depending on installed pollution control technology and other factors. Emissions from the New Jersey and Pennsylvania area create relatively high damages per ton due to pollution transport patterns, so the assumption that the damage per unit of emissions is the same as oil generation might be reasonable.

In contrast, as the marginal emission rate rises above 0.52, more weight is placed on the value for oil generators. At an intermediate marginal emission rate for CO₂ of 0.75, the value for gas will receive a weight of $\frac{1.1-0.75}{1.1-0.52} = 0.6$ while oil will receive a weight of $\frac{0.75-0.52}{1.1-0.52} = 0.4$. Clearly, for a marginal emission rate for CO₂ equal to 1.1, oil will receive a weight of 1 while gas will receive zero weight, meaning that DER injections would avoid generation from oil generators, and bring both high local and global pollutant environmental benefits.

B. Emission and Damage Rates

To calculate the value of avoided external damages for gas and oil generators in the state, we combined emissions data from eGrid and NEI with damage estimates from COBRA and EASIUR, as described in the previous sections. Table 1 shows state-wide, average emission rates for oil and gas generators. One can see that emission rates of natural gas generation are lower than those for oil generation for all pollutants. Note that when we calculated the value stacks for each zone, we used zone-specific emissions and damages.

Table 1: Generation-weighted State-average Emission Rates (kg/kWh) For Gas and Oil Generators

Fuel Type	NO _x	PM _{2.5}	SO ₂	CO ₂
Natural Gas	0.0003	0.00000	0.0000	0.52
Oil	0.0031	0.00003	0.0027	1.10

Note: Data come from eGrid 2016 and NEI. All values are generation-weighted averages across generators in all zones of New York.

The Subgroup calculated the value of avoided emissions using two different runs of the COBRA model—high and low damages—and the EASIUR model. Figures 5-7 below show hourly value stacks for three representative zones and each of these models. Zone A is a low-emission zone where zero-emitting resources are marginal during many hours of the day. Zone J is the highest-emitting zone, with non-gas resources are on the margin routinely. Finally, Zone K experiences emissions between these two extremes.

The average value of avoided emissions is about 2.8 cents per kWh in Zone A for the EASIUR model, 2.6 cents per kWh for the low damage COBRA model, and 3.6 cents for the high damage COBRA model. In Zone J, in contrast, values are more than twice as high. The value is 7.4 cents per kWh for the EASIUR model, 8.4 cents per kWh for the low damage COBRA model, and 16.2 cents per kWh for the high damage COBRA model. In Zone K, EASIUR again returns values that are between the low and high estimates produced by COBRA: the value is 6.2 cents per kWh using EASIUR, 4.8 cents per kWh using the low damage COBRA model, and 8.0 cents per kWh using the high damage COBRA model.

The figures reveal that the value is not constant during the day. One can see that in all locations, the highest value occurs between 10 a.m. and 6 or 7 p.m. The intra-daily pattern of value is determined by the underlying CO₂ marginal emissions rates and is common across the three damage models. One can

also see that EASIUR damages come predominantly from NO_x emissions, while COBRA damages are more equal across the three local pollutants.

Figure 5: Value Stack Using EASIUR Damages

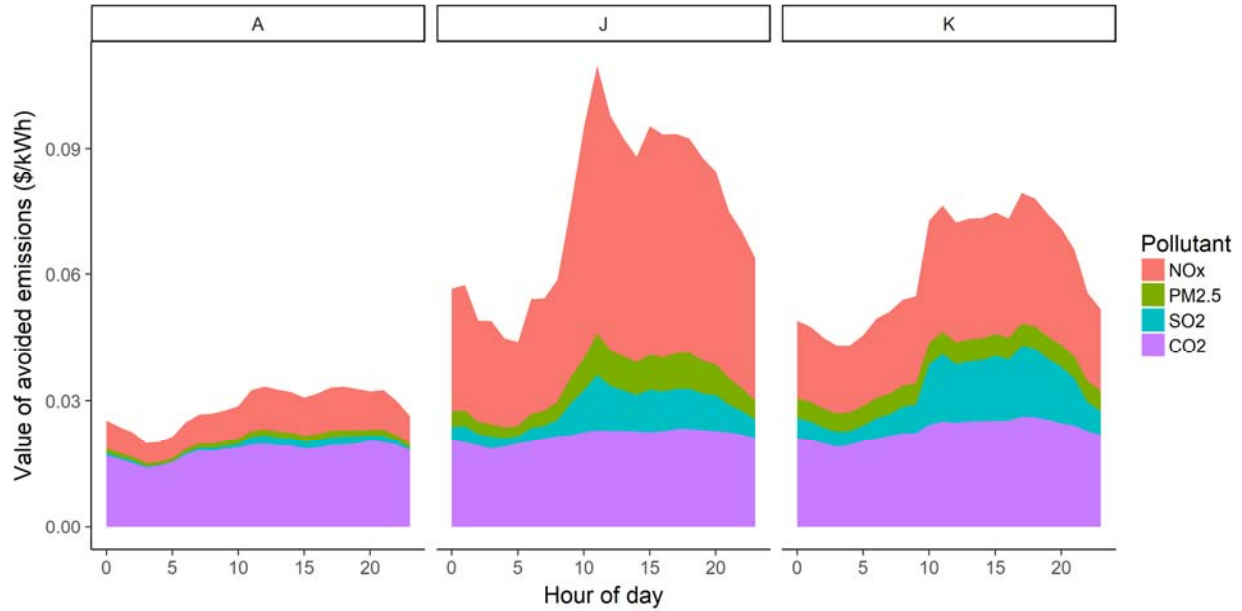


Table 2: Average Zonal Values Using EASIUR Damages (\$/kWh)

	A	B	C	D	E	F	G	H	I	J	K
NO _x	0.008	0.004	0.001	0.004	0.007	0.009	0.018	0.015	0.015	0.040	0.024
PM _{2.5}	0.001	0.002	0.001	0.011	0.006	0.002	0.006	0.005	0.005	0.006	0.005
SO ₂	0.001	0.001	0.001	0.001	0.001	0.004	0.004	0.004	0.004	0.007	0.010
CO ₂	0.018	0.018	0.018	0.018	0.018	0.021	0.022	0.022	0.022	0.022	0.023
Total	0.028	0.026	0.020	0.033	0.033	0.036	0.050	0.046	0.046	0.074	0.062

Figure 6: Value Stack Using Low COBRA Damages

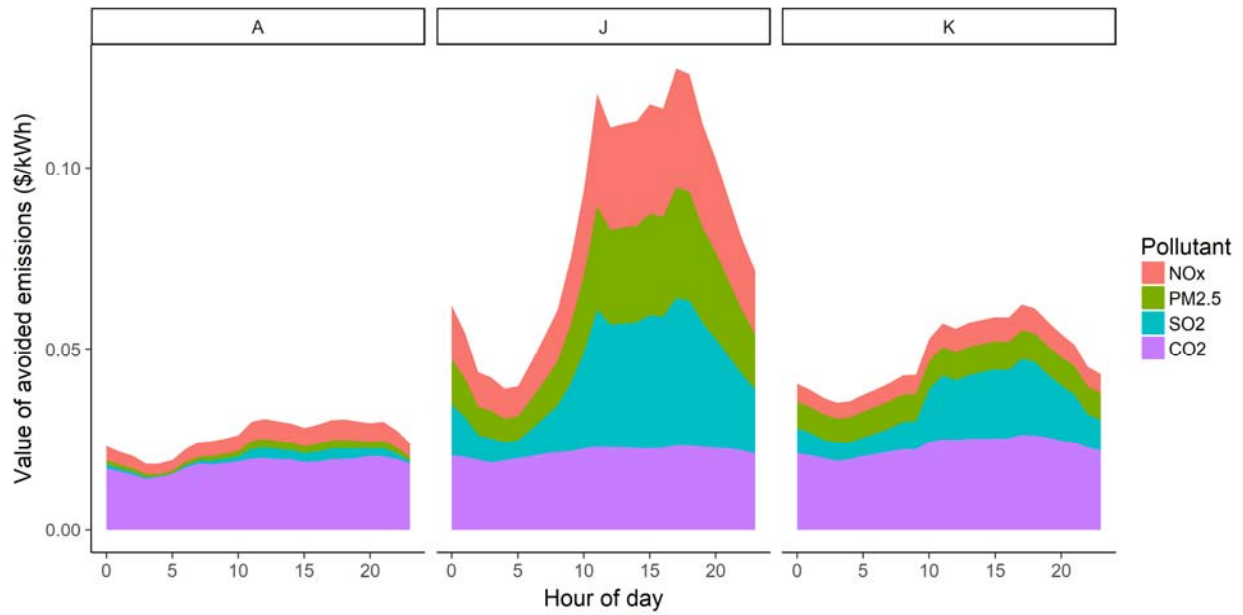


Table 3: Average Zonal Values Using Low COBRA Damages (\$/kWh)

	A	B	C	D	E	F	G	H	I	J	K
NOx	0.004	0.003	0.000	0.002	0.004	0.004	0.010	0.007	0.007	0.021	0.006
PM _{2.5}	0.002	0.003	0.001	0.007	0.005	0.004	0.011	0.007	0.007	0.019	0.008
SO ₂	0.002	0.002	0.001	0.000	0.002	0.006	0.006	0.007	0.007	0.023	0.012
CO ₂	0.018	0.018	0.018	0.018	0.018	0.021	0.022	0.022	0.022	0.022	0.023
Total	0.026	0.026	0.020	0.027	0.029	0.035	0.049	0.042	0.042	0.084	0.048

Figure 7: Hourly Zonal Value Stack Using High COBRA Damages

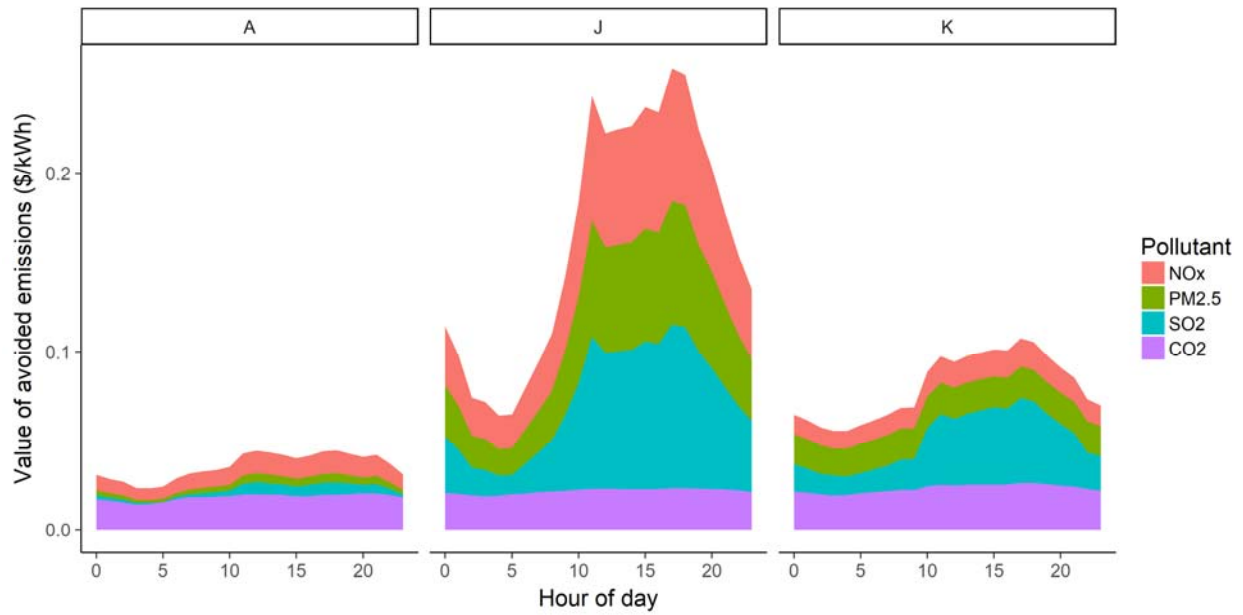
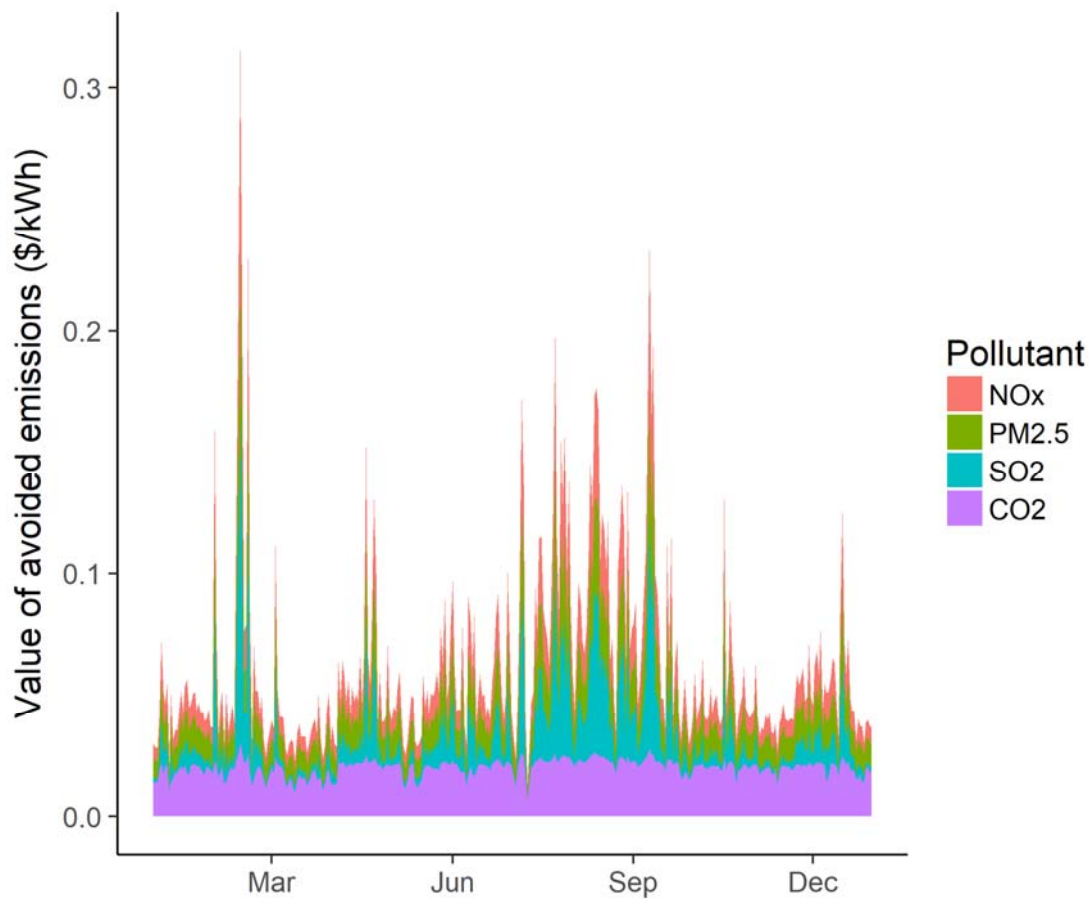


Table 4: Average Zonal Values Using High COBRA Damages (\$/kWh)

	A	B	C	D	E	F	G	H	I	J	K
NOx	0.010	0.006	0.001	0.003	0.008	0.010	0.023	0.016	0.016	0.047	0.013
PM _{2.5}	0.004	0.007	0.001	0.015	0.012	0.009	0.024	0.016	0.016	0.042	0.017
SO ₂	0.004	0.004	0.001	0.001	0.004	0.013	0.015	0.015	0.015	0.051	0.027
CO ₂	0.018	0.018	0.018	0.018	0.018	0.021	0.022	0.022	0.022	0.022	0.023
Total	0.036	0.035	0.022	0.038	0.042	0.053	0.083	0.069	0.069	0.162	0.080

Finally, Figure shows that damages also vary over the year. The figure shows the state-wide average, daily value stack for each day of 2016 using the high damage COBRA model. Additional figures showing the daily value stack using the low damage COBRA and EASIUR models can be found in Appendix A. One can see that on days when high-emitting resources are often on the margin, as occurred in the late winter and summer of 2016, the value can spike much higher than the average. A higher temporal granularity to the value calculation will allow dispatchable DER to capture this value and, therefore, provide economically efficient incentives for dispatch.

Figure 8: Daily Value Stack Using High COBRA Damages



IV. Valuation of Local Pollutants in Other States

The Commission has been a leader in the incorporation of tools such as COBRA and the Social Cost of Carbon into state electricity policies in order to value the marginal external damages associated with air pollution. However, New York is not alone, and the experience of other states may inform New York's efforts to develop more granular "E" values as part of this VDER proceeding.

A. California

California has used a number of tools to estimate the marginal damages of both local and global air pollutants in the context of air quality management and energy policy.

BAAQMD Clean Air Plan. As discussed above, the BAAQMD, a state agency tasked with regulating stationary sources of air pollution in nine Bay Area counties, developed what is probably the most comprehensive custom air pollution modeling tool as part of its Bay Area 2016 Clean Air Plan.⁵³ The Clean Air Plan is a multi-pollutant plan that includes controls for ozone, particular matter, air toxics, and greenhouse gases. In order to analyze and compare different pollution control measures, the BAAQMD developed its "multi-pollutant evaluation method" (MPEM), which uses geographic-specific data and complex air transport modeling to estimate and monetize neighborhood-level health, economic, social, and environmental costs associated with increased air pollution.⁵⁴

For local pollutants, the BAAQMD established a detailed methodology for each step needed to translate changes in air pollution emissions to monetized damage estimates included: (1) how much a control measure would reduce emissions, (2) how changes in emissions result in changes in ambient concentrations on a 4 km by 4 km grid using complex air transport modeling, (3) how change in ambient concentrations will effect exposure of residents given population density, (4) how reduced exposure will impact health endpoints including emergency room visits, reduced respiratory symptoms, and deaths, and (5) how those health endpoint changes result in monetized benefits. To the extent that the Commission adopts a long-term plan for building a custom model to more accurately measure the benefits of avoided local pollution in New York State, the MPEM can be a useful starting point.

For greenhouse gas emissions the MPEM uses the IWG Social Cost of Carbon 2.5% discount rate option because use of higher discount rates "would raise ethical issues since putting a near-zero value on future benefits suggests that as a society we do not care about the future beyond another generation or two."

CPUC Societal Cost Test. A California Public Utilities Commission proceeding is currently underway to develop a Societal Cost Test for evaluation of bids submitted in response to competitive solicitations by

⁵³ See generally Bay Area Air Quality Mgmt. District, Spare the Air Cool the Climate: Final 2017 Clean Air Plan (2017), http://www.baaqmd.gov/~media/files/planning-and-research/plans/2017-clean-air-plan/attachment-a_-_proposed-final-cap-vol-1-pdf.pdf?la=en.

⁵⁴ See David Fairley & David Burch, Bay Area Air Quality Management District, Multi-Pollutant Evaluation Method Technical Document: 2016 Update (2016), http://www.baaqmd.gov/~media/files/planning-and-research/plans/2017-clean-air-plan/mpem_nov_dec_2016-pdf.pdf.

public utilities as part of distributed resource planning.⁵⁵ In March 2018, the California Public Utilities Commission Staff (Staff) issued a proposal for the use of certain tools to value both local pollutants and greenhouse gases as part of the Societal Cost Test.⁵⁶ The California Public Utilities Commission has not yet issued a final order in this docket, but the Staff proposal provides a valuable perspective on various policy choices that the Commission will be facing when selecting methodologies as part of the Value of DER proceeding.

For local pollutants, the California Public Utilities Commission Staff recommended using COBRA as a “first step” “until such time as a more robust model for determining the air quality impacts of electricity generation can be developed, such as BenMAP.”⁵⁷ Staff used a high value estimate of damages because COBRA does not currently include damages associated with some pollutants, including ozone, and because it ignores emissions from electricity imported from other states. This approach is consistent with our recommendations that the Commission use an available model now and work to develop more robust modeling tools in the future.

For greenhouse gases, the Staff recommended the use of the IWG Social Cost of Carbon as the most appropriate tool for monetizing avoided emissions. Specifically, the Staff recommended use of the 3% discount rate, 95th percentile damage estimate methodological option included as part of the IWG Social Cost of Carbon in order to account for damages not included in current climate models.

B. Maryland

Value of Solar Study. In April 2018, the Maryland Public Service Commission released a value of solar study, which calculated the benefits and costs of utility scale and distributed solar resources.⁵⁸ As part of that analysis, the study included a quantification of the environmental benefits of in-state solar generation. This included quantification of avoided local pollution— SO₂, NO_x, and PM_{2.5}—and greenhouse gas pollution— CO₂. Emission changes were calculated using a proprietary electric market simulation model. For local pollution, the value of emission changes was calculated as the reduction in monetized health damages using COBRA. The study reported both high and low damage estimates at a 3 percent discount rate. For greenhouse gases, the study used the IWG Social Cost of Carbon and values from the central estimate.

C. Maine

Value of Distributed Solar Study. The Maine Public Utilities Commission (ME PUC) was required by statute to produce a report that determines the value of distributed solar energy generation in the State

⁵⁵ Cal. PUC, Order Instituting Rulemaking to Create a Consistent Regulatory Framework for the Guidance, Planning and Evaluation of Integrated Distributed Energy Resources, Rulemaking 14-10-003.

⁵⁶ Cal. PUC, Distributed Energy Resource Cost-Effectiveness Evaluation: Further Recommendations on the Societal Cost Test (2018), <http://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M212/K023/212023660.PDF>.

⁵⁷ *Id.* at 12.

⁵⁸ Daymark Energy Advisors, Benefits and Costs of Utility Scale and Behind the Meter Solar Resources in Maryland (April 10, 2018), <http://www.psc.state.md.us/wp-content/uploads/MD-Costs-and-Benefits-of-Solar-Draft-for-stakeholder-review.pdf>.

and evaluates implementation options.⁵⁹ This value of distributed solar study included an “E” value-equivalent, including valuing avoided local air pollution—NO_x and SO₂—and greenhouse gas emissions—CO₂. For local pollutants, the ME PUC used per-ton monetized values used by EPA in its cost-benefit benefit analysis for the *proposed* Clean Power Plan rule. These values are based on health benefits caused by reduced secondary PM_{2.5} that results from reduced emission of SO₂ and NO_x, which act as PM_{2.5} precursors. Specifically, the ME PUC used the mid-point of the high and low values EPA calculated for 2020 in the East Region (all states east of Colorado), discounted at a 3-percent rate.

For greenhouse gases, Maine used the IWG Social Cost of Carbon 3-percent central estimate as the foundation. However, because carbon costs are already partially embedded in existing energy valuation as a result of carbon emissions caps under the Regional Greenhouse Gas Initiative (RGGI), the study used a net Social Cost of Carbon value. This net value was calculated by subtracting the embedded RGGI carbon allowance costs from the total Social Cost of Carbon.

D. Minnesota

Integrated Resource Planning. By statute, the Minnesota Public Utilities Commission (MN PUC) is required to consider “the environmental costs associated with each method of electricity generation” when evaluating utility resource plans.⁶⁰ Since 1997, the MN PUC has considered environmental costs associated with both local air pollution—NO_x, SO₂, and PM_{2.5}—and greenhouse gases—CO₂.⁶¹ The MN PUC adopted a damage-cost methodology for calculating these costs, rather than alternative approaches such as the abatement costs or consumer willingness-to-pay methods. In 2018, the MN PUC issued an order updating the values used to quantify damages associated with various resource options based on recommendations from an Administrative Law Judge developed as part of a contested proceeding.⁶²

For local pollutants, the MN PUC adopted a custom approach to valuation. Air quality was modeled using the CAMx air-quality model. The health effects that were monetized were limited to mortality caused by secondary PM_{2.5} exposure, using a set dose-response function, and a range of values for monetizing changes in the risk of death (called the “value of statistical life” or VSL). Separate values were developed for urban/rural/metro-fringe geographic areas based largely on population density.

For greenhouse gases, the MN PUC accepted the IWG Social Cost of Carbon as the best framework for assessing marginal external damages of electricity generation options, but made methodological changes related to the time horizon for assessing future climate damages. It requires the use of a high and low Social Cost of Carbon value. The high value is based on the 3-percent central estimate values (rejecting the ALJ recommendation to use the 2.5 percent discount rate) and a 2300 time-horizon. The low values are based on the 5-percent discount rate and a 2100 time-horizon.

⁵⁹ Maine Public Utilities Commission, Maine Distributed Solar Valuation Study (2015), https://www.maine.gov/mpuc/electricity/elect_generation/documents/MainePUCVOS-ExecutiveSummary.pdf.

⁶⁰ 1993 Minn. Laws, ch. 356, § 3 (codified at Minn. Stat. § 216B.2422, subd. 3)

⁶¹ Minn. PUC, Order Establishing Environmental Cost Values. Docket No. E-999/CI-93-583 (January 3, 1997).

⁶² Minn. PUC, Order Updating Environmental Cost Values, Docket No. E-999/CI-14-643 (January 3, 2018).

Value of Solar Tariff. Minnesota has implemented a value of solar tariff that sets compensation for solar generation based, in part, on the environmental value of avoided air pollution emissions.⁶³ Minnesota incorporated the value of avoiding both local pollutants—NO_x, SO₂, and PM_{2.5}—and greenhouse gases—CO₂. For local pollutants, the MN PUC adopted values based on the resource planning analysis requirements under the “urban” scenario. The methodology for calculating avoided local pollution damages is similar to that employed for integrated resource planning, described above. For greenhouse gases, the MN PUC adopted the IWG Social Cost of Carbon 3-percent discount rate central estimate, without the time-horizon adjustments it requires for resource planning.

⁶³ Minn. Dep’t of Commerce, Minnesota Value of Solar: Methodology (2014), <http://mn.gov/commerce-stat/pdfs/vos-methodology.pdf>.

Appendix A – Additional Figures

Figure A1: State-average Daily Value Stack Using EASIUR Damages

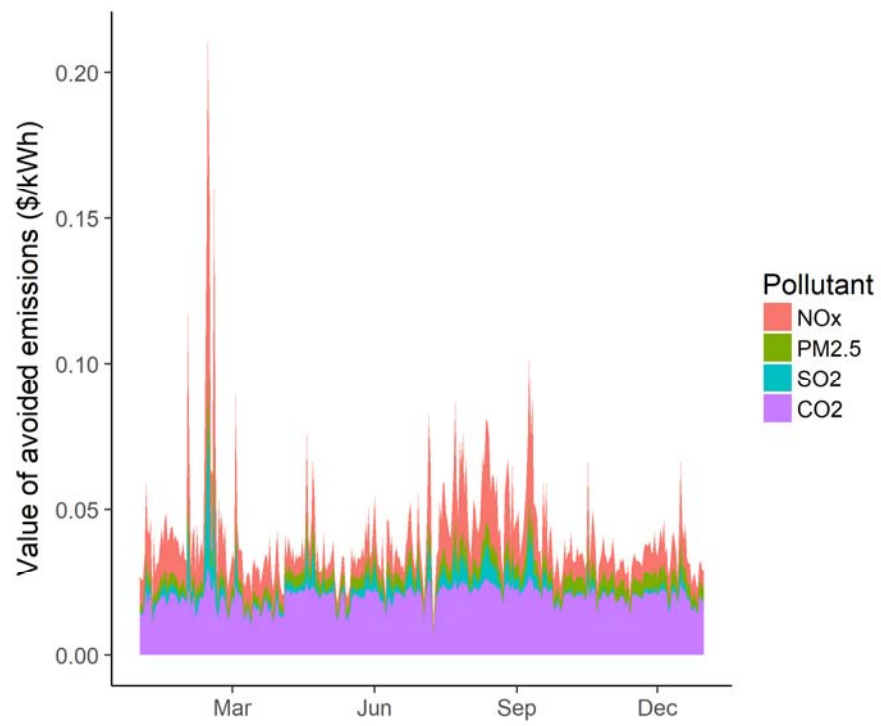


Figure A2: State-average Daily Value Stack Using Low COBRA Damages

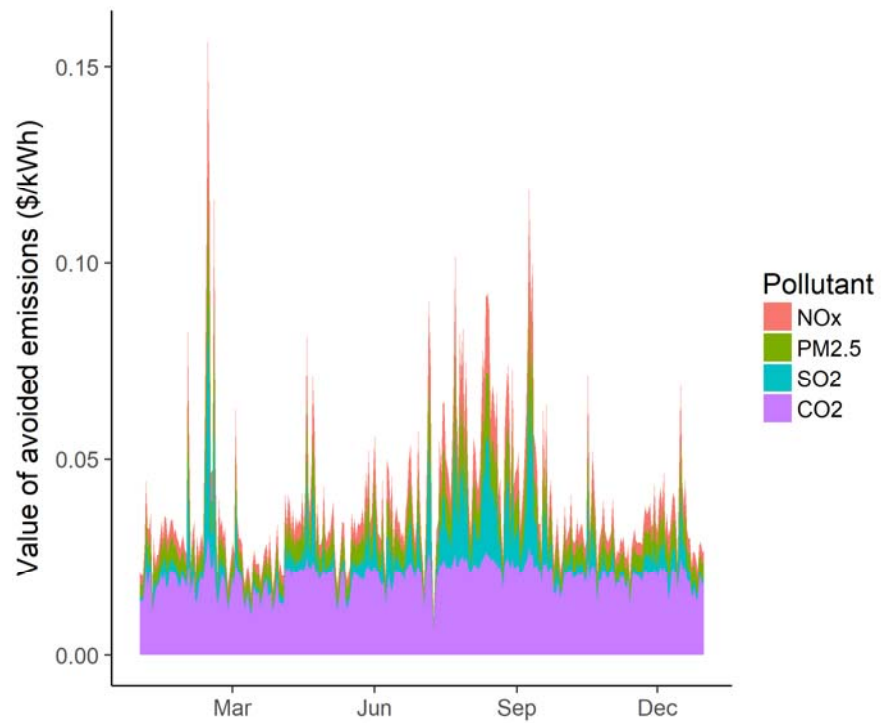


Figure A3: Zone-specific Hourly Value Using EASIUR Damages

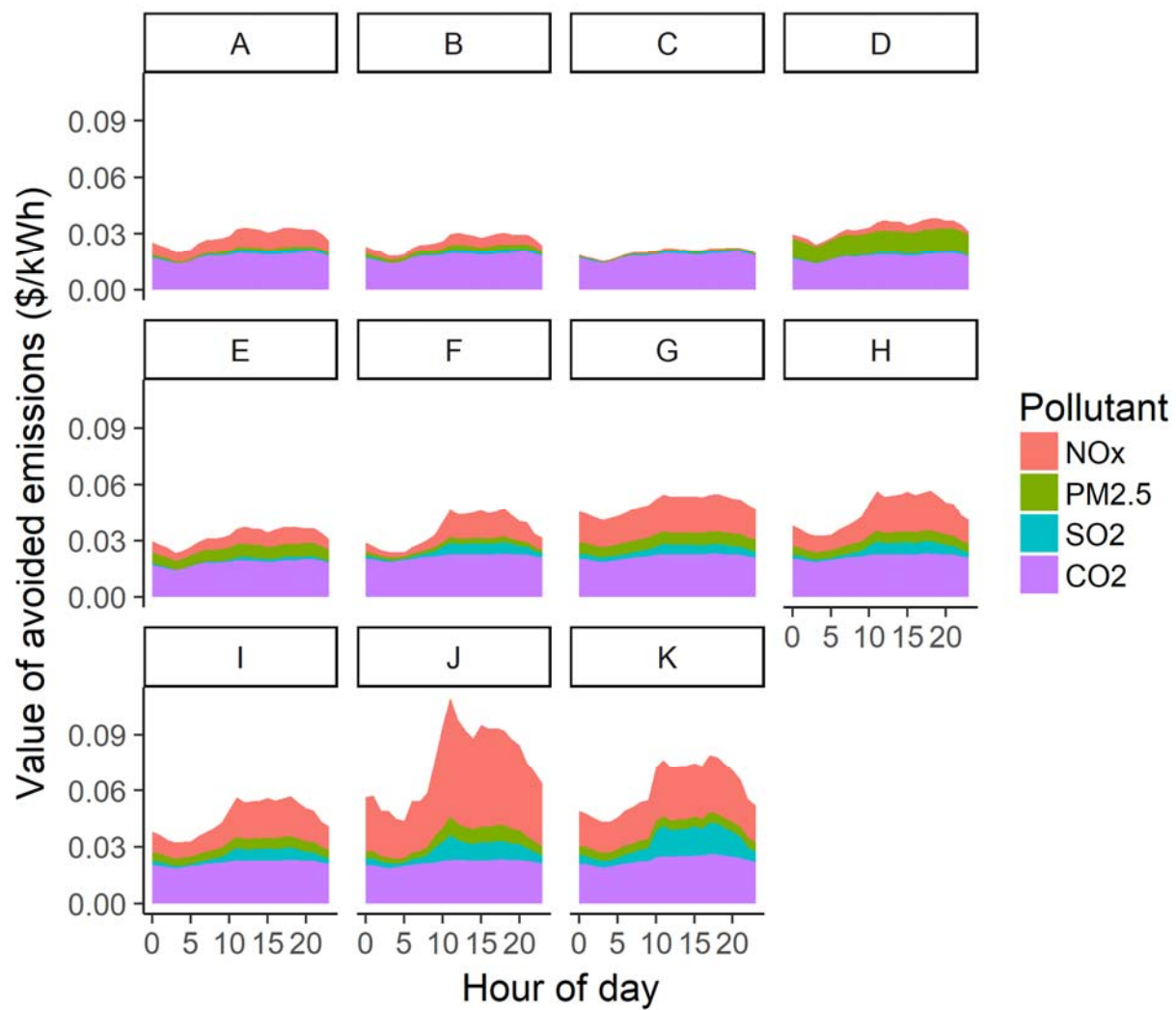


Figure A4: Zone-specific Hourly Value Using Low COBRA Damages

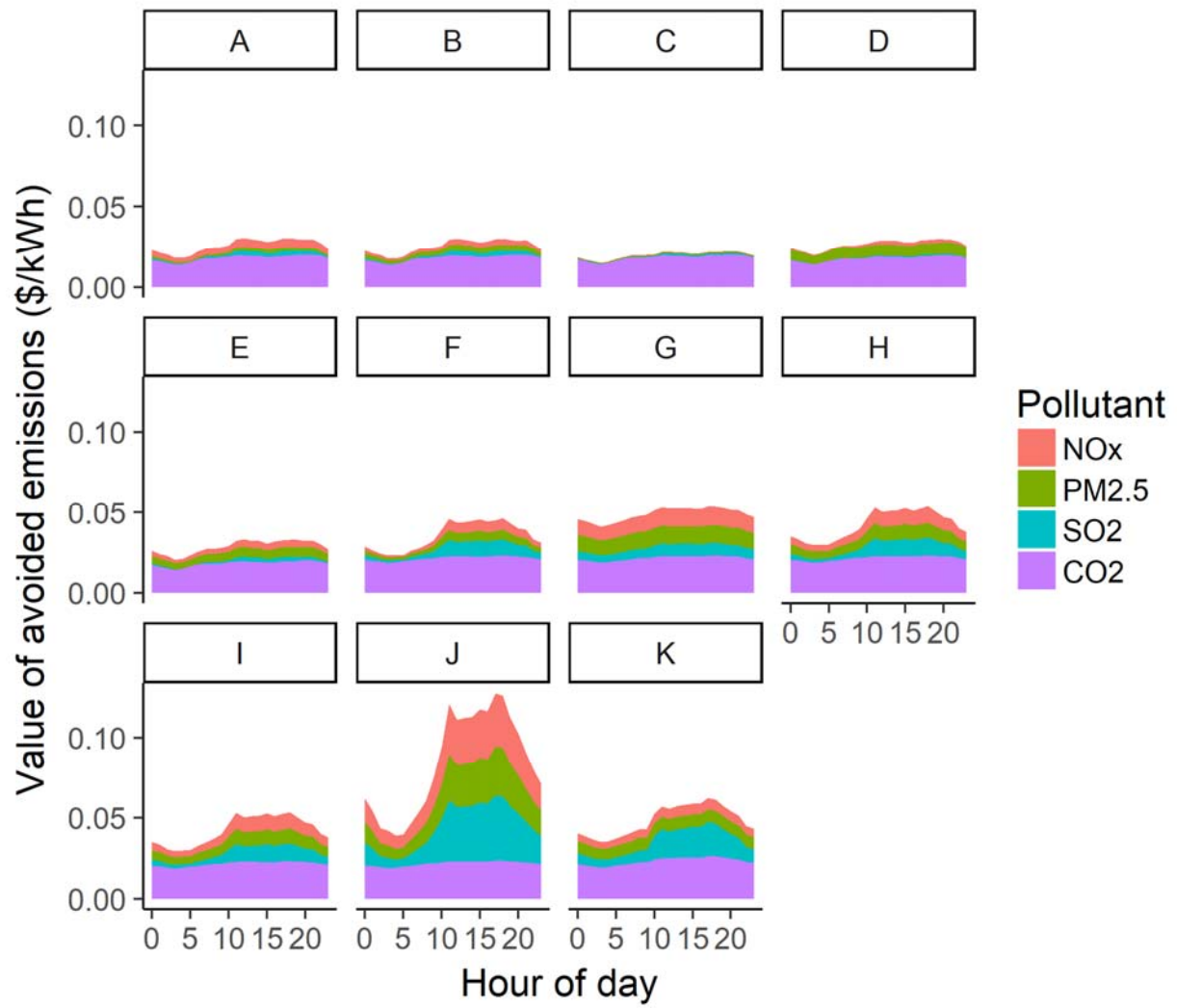
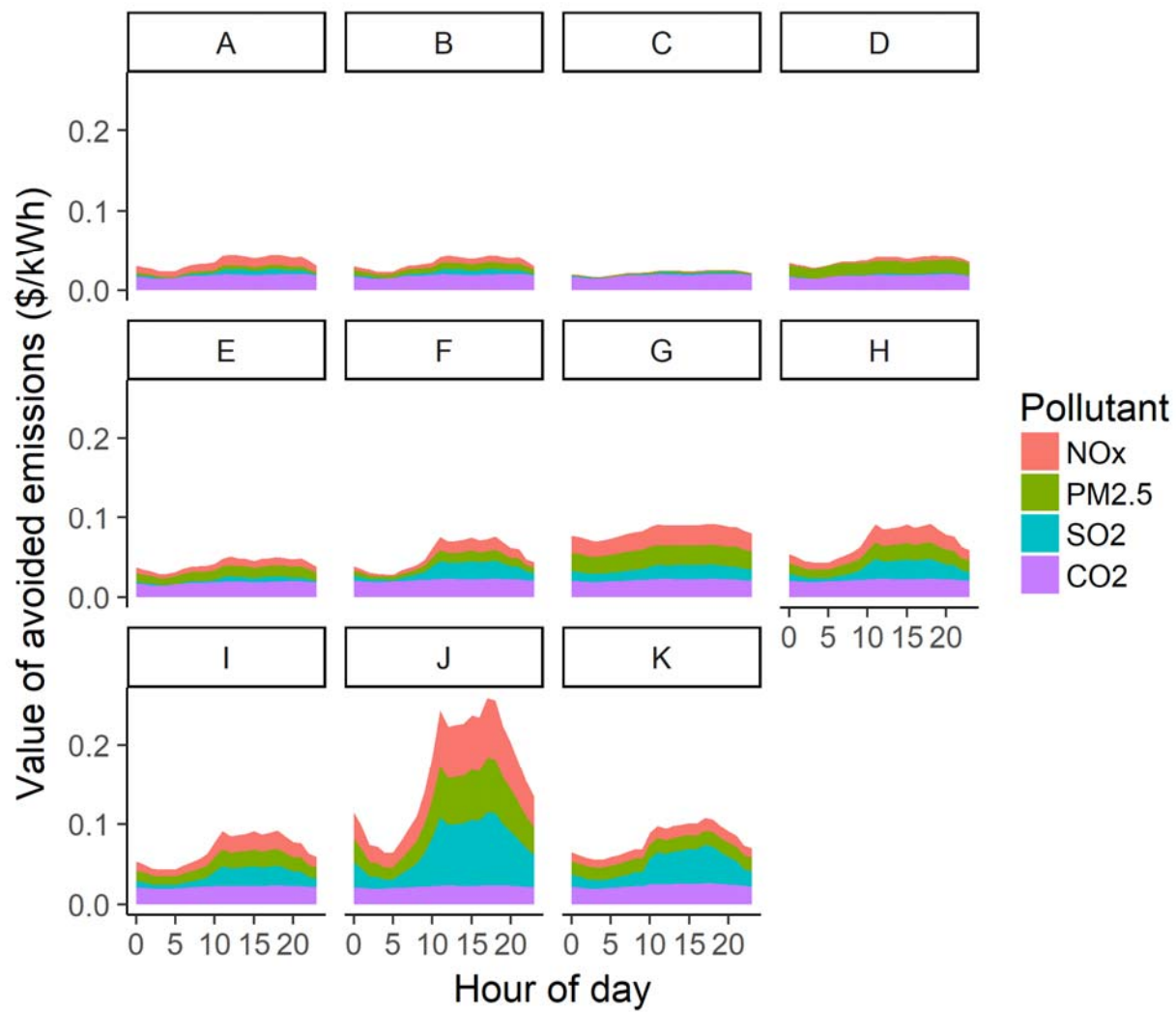
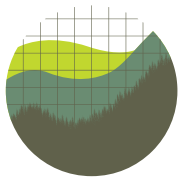


Figure A5: Zone-specific Hourly Value Using High COBRA Damages



Appendix B – Policy Integrity Valuing Pollution Reductions Report



Institute for
Policy Integrity
NEW YORK UNIVERSITY SCHOOL OF LAW

ELECTRICITY POLICY INSIGHTS



Valuing Pollution Reductions

*How to Monetize Greenhouse Gas and Local Air Pollutant
Reductions from Distributed Energy Resources*

March 2018
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Burcin Unel, Ph.D.
Avi Zevin

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This report does not necessarily reflect the views of NYU School of Law, if any.

Executive Summary

Distributed energy resources (DERs)—grid-connected, small-scale electric generators such as rooftop solar installations, micro-turbines, combined heat and power systems, customer backup generators, and distributed energy storage systems—are a growing component of the U.S. electric system. As DERs have become more prominent, state electric utility regulators have begun efforts to more accurately compensate DERs by paying for each of the benefits that they provide.

One such benefit is the avoidance of environmental and public health damages from air pollution (including local air pollution and greenhouse gas emissions) that would have been caused by generation resources that have been displaced by the DERs. This report lays out a practical methodology for calculating this environmental and public health value. It identifies existing tools that states can use, with varying degrees of specificity, accuracy, and complexity, to monetize these pollution reductions. State utility regulators can use the steps outlined here, weighing tradeoffs between accuracy and administrability, to implement their own program to compensate DER for environmental and public health benefits. Regulators can monetize air pollution reductions that DERs provide by using a five-step method:

Step 1 determines what generation will be displaced by DERs. The most accurate methods for determining displaced generation require working with grid operators and, potentially, local distribution utilities, to obtain needed data on which bulk system generators would have operated in the absence of DERs. If sufficient data is not available, utility regulators can use electricity system simulation models to estimate which resources would have operated in the absence of DERs.

Step 2 quantifies the emissions rates for displaced generators. Emissions rates of existing resources vary widely, and therefore, the magnitude of the environmental and public health benefits of DERs will as well. Emissions rates depend on a generator's attributes, including fuel type (for example, coal, oil, natural gas, or renewable), electricity generation technology (for example, inefficient steam boilers or efficient combined-cycle technology), pollution control equipment, and operational practices like capacity factor.

Emission rates of existing generators can be determined based on those generators' historical, measured emissions rates, or can be estimated using engineering analyses, given known information about fuel type, generation technology, pollution control equipment, and operational practices. Databases of historical emissions rates for specific plants and of emission factors broken out by generator attribute (such as fuel type, generation technology, and pollution control equipment) are also available.

Step 3 calculates the monetary value of the damages from emissions identified in Step 2. Air pollutants cause damage to human health, impair ecosystems, harm crops, and make it harder for workers to be productive. Given knowledge of the emissions rate for a power generator, utility regulators can calculate those damages as a function of:

- The type of the pollutant. Particulate matter, especially fine and ultra-fine particulates, cause severe health damages, including death. Oxides like SO₂ and NO_x break down into particulate matter and combine with other pollutants to form asthma-causing ozone pollution. Toxic heavy metals like

mercury and lead cause rapid health deterioration even at low concentrations. Greenhouse gases lead to climate change. Researchers have developed monetized damages estimates per unit of emissions for each of these pollutants.

- The location of emissions. Each unit of a pollutant emitted in population-dense areas or in areas with highly vulnerable populations will cause more damage. Emissions also interact with environmental conditions such as prevailing winds to carry pollutants away from the point of emissions. Damage estimates can be modified to account for these concerns.
- The timing of emissions. Some pollutants, such as ozone, only form when precursors are exposed to direct sunlight. Therefore, emissions that occur at night or in winter may cause less damage than those during the day or in the summer. Granular damage estimates account for these timing issues.

A method that accounts for all of these factors would lead to the most accurate calculations of damage per unit of emissions. However, data constraints and ease of use might make alternative, less granular methods more desirable. There are multiple tools produced by various researchers as well as EPA that provide estimates of pollution damages at the county level, and many of these tools allow for partial customization to meet specific needs of regulators.

Step 4 uses the emissions rates from Step 2 and damage estimate per unit of emissions from Step 3 to monetize the value of avoided emissions from displaced generation. Adjustments are needed if existing policies already put a price on emissions of some or all of the pollutants covered in Steps 1-3.

Step 5 takes into account any emissions produced by the DER itself. DERs such as diesel generators or combined heat and power generators emit pollutants. To arrive at an accurate environmental and public health value, those emissions and the damage they cause must also be taken into account. If damage per unit of generation from the DER is high enough, then the net environmental and public health value of the DER could be negative.

Distributed energy resources can provide substantial value to a state by reducing air pollution from conventional electric generators and the resulting environmental and public health damages. DERs can be particularly valuable to the extent that they avoid local air pollution imposed on vulnerable populations. As state utility regulators implement new compensation policies for these resources, those policies should include payment for DERs' environmental and public health value.

This report presents a straightforward five-step methodology that can be used to calculate this value in a technology-neutral manner while relying on existing, readily accessible tools. The methodology outlined in this report is flexible enough to accommodate a variety of data and resource constraints. State regulators can weigh the tradeoffs between accuracy and administrability of different methods to calculating environmental value, pick the tools that are most accurate given the tradeoffs, and then update their methodology when feasible.

While more comprehensive reforms such as an economy-wide tax on greenhouse gases and local air pollutants are needed to fully value the environmental and public health benefits of all DERs, this methodology would allow utility regulators to implement a DER compensation scheme that incentivizes DERs when and where they are most beneficial to the society.

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Introduction

The electric grid is quickly evolving from its traditional structure, where electricity is generated by large power plants located far from end-users, into a multi-dimensional platform. The modern grid allows a variety of new distributed resources that are located near end-users, such as solar panels, energy storage, and demand response, to provide a multiplicity of electricity services. With rapid innovation and declines in costs, these “distributed energy resources” (DERs) are becoming an integral part of the modern grid, and thus, creating new challenges for regulators.¹

As technology is transforming the grid, policymakers around the nation are working to reform utility regulation in order to harness the full benefits that these technological changes offer. A number of states have initiated proceedings to implement compensation schemes for electricity generated from DERs, or a subset of DERs, that reflect all of the benefits that those resources provide.²

DERs help reduce the need for generation from large-scale generators interconnected to the transmission system (“bulk system generators”) such as fossil-fuel-fired power plants, which are often costly to build and highly polluting. Depending on the type of DER, they do so in two ways: by reducing customer demand at a given time, or by actually generating electricity. DERs such as demand response and energy efficiency reduce customer demand for electricity at a particular time. Other DERs, such as distributed solar, generate electricity, which can then be used by consumers to offset grid purchases and/or can be exported to the grid. Energy storage can provide benefits by shifting consumer demand, by charging and discharging at different times.

By avoiding the need for generation from the bulk system, DERs can provide many benefits to grid such as avoided energy costs, avoided or deferred capacity costs, and reduced line losses.³ This report, however, focuses on one regularly overlooked category in utility regulation: environmental and public health benefits.

Bulk system generators often burn fossil fuels—coal, natural gas, and petroleum—or biogenic fuels—agricultural and wood waste, municipal solid waste, animal waste, and landfill gas—and in doing so, they emit air pollutants. When DERs avoid the need for such bulk system generation, they can help reduce air pollution, benefiting society at large. Currently, however, these benefits are not explicitly valued.

Air pollutants emitted by power plants

Combustion of fossil fuels and biogenic fuels results in the emission of air pollutants, which fall into several categories. Air pollutants that affect human health and are dispersed in the ambient air are referred to under the federal Clean Air Act as “**criteria pollutants**.” These include particulate matter (PM₁₀), fine particulate matter (PM_{2.5}), sulfur dioxide (SO₂), nitrogen oxides (NOx), and carbon monoxide (CO). These pollutants also combine in the atmosphere with each other and with volatile organic compounds (VOCs) to make other “secondary” criteria pollutants, including PM_{2.5} and ozone.

In addition, combustion releases **greenhouse gases**—including carbon dioxide (CO₂) and nitrous oxide (N₂O)—that alter the climate and so cause a wide range of disruptive health, social welfare, and environmental effects.

Finally, combustion of some fuels results in emission of **hazardous air pollutants** (HAPs), also referred to as “air toxics,” which cause significant damage even in small amounts. This category includes mercury and ammonia.

Air pollution is a textbook example of what economists call an “externality.” Externalities are costs or benefits of market transactions that are incurred by parties other than the market participants, and thus are not taken into account by market participants. When externalities are present, market prices do not reflect the external costs and benefits of production or consumption, and therefore fail to provide an economically efficient signal for the true social value of the particular good or service, leading to an inefficient outcome. For example, because fossil-fuel-fired power plants are not paying for the environmental and public health damages their electricity generation causes, we get more air pollution than is socially desirable.

When negative externalities are present, social welfare can be increased by imposing a tax on the source of the externality—in this case, the emission of air pollutants—based on the amount of external damage caused. In the absence of efficient pollution taxes, alternative policies can help improve the efficiency of market outcomes.

One such policy approach is to pay generating resources that reduce air pollution. DERs provide environmental and public health benefits by displacing generation from other resources that would have emitted more air pollution.⁴ Therefore, utility regulators can improve social welfare by ensuring that low and zero-emitting DERs are paid for the environmental and public health benefits they produce by displacing higher-emitting generation.

Appropriately valuing these benefits involves identifying the extent to which air pollution is avoided due to DERs, and then monetizing the economic, health, and climate damages those emissions would have caused. This report lays out a practical, technology-neutral methodology for identifying those values. Utility regulators can incorporate this methodology into proceedings aimed at establishing compensation structures for DERs.

It is important to note that, ideally, the same framework would be used to compensate all types of DERs for all the value they provide. However, because the price signals for load reductions manifest as avoided electricity purchases (at the retail electricity rate that customers pay), such comprehensive compensation would require complementary retail rate reforms in order to internalize the externalities.⁵ Addressing this is beyond the scope of this report.

The methodology outlined in this report, therefore, is appropriate for compensating energy supplied to the grid by DERs. This limitation likely leads to an underestimation of the environmental and public health benefits of DERs that reduce on-site electricity consumption. However, despite the limitation of the methodology outlined here, compensating even just injections to the grid for the environmental and health benefits DERs provide would significantly improve social welfare.

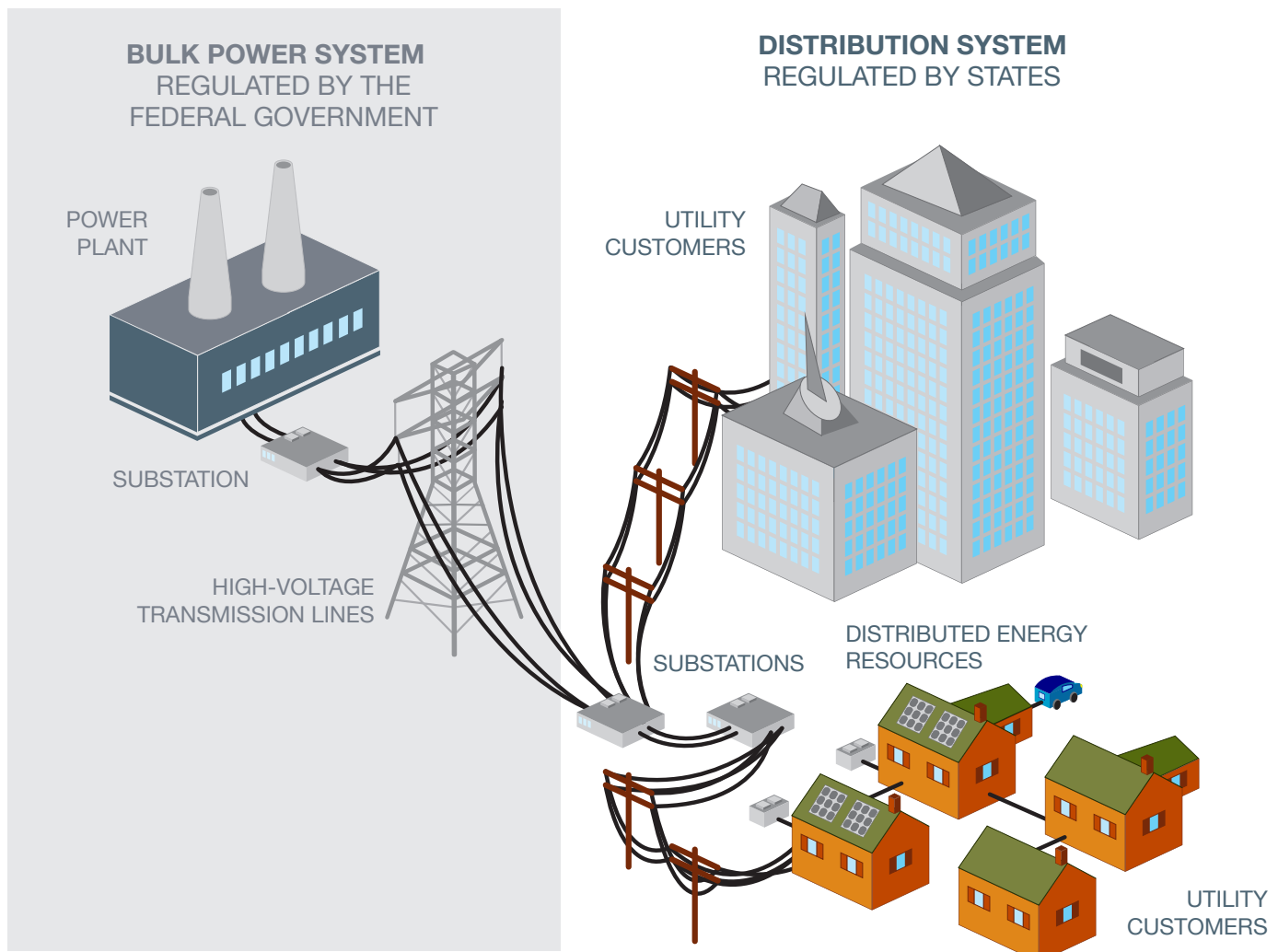
A brief overview of distributed resources, utility regulators, and grid operators

The regulation of electricity is divided between the federal government and the states.⁶ Federal regulators have primary responsibility over interstate transmission and wholesale electricity, or the bulk power system, and state regulators have primary responsibility over the distribution system.

State regulators, commonly called “public utility commissions” or “public service commissions,” are responsible for regulating local distribution utilities and setting retail rates, as well as deciding on other state-level policies such as DER compensation, renewable portfolio standards, and energy efficiency programs.

In much of the country, the bulk power system, consisting of most generators and large transmission lines, is regulated by the Federal Energy Regulatory Commission and operated by grid operators called “independent system operators” (“ISOs”) or “regional transmission organizations (“RTOs”). ISOs/RTOs ensure that supply and demand of the bulk power system are constantly balanced using complex algorithms that take into account the location of both generators and demand, the costs of generation, and congestion on the transmission system. Grid operators dispatch resources from least expensive to most expensive (taking into account the congestion on the transmission system), until demand has been met.

Figure 1: Regulatory Domains of the Electric Grid



Valuing Environmental Benefits of Distributed Energy Resources – An Overview

Public Utility Commissions can calculate the environmental and public health value of DERs based on emissions avoided by the DER and the monetary value of the damage that those emissions would have caused. These two values will depend on the location of the DER and the avoided emissions, the time of day and year when emissions are avoided, and the type of pollutants avoided.⁷

DERs in different locations or generating at different times will displace different sources of generation, with various levels of emissions. Because different generators use a variety of fuel types, electricity generation technologies, control equipment, and operation practices that result in a wide range of air pollutant emissions rates, the type of generators displaced is an important driver of the value. DERs are worth more to society when they offset generation from higher-emitting sources.⁸

DERs are also more valuable when they reduce air pollution in areas with high population density and more vulnerable populations. The time of year also matters because NO_x and VOC emitted in the summer carry greater health consequences, due to their role in the formation of ozone in the presence of sunlight. Therefore, DERs that can reduce pollutants in such areas and times are more valuable.

Finally, different pollutants cause different levels of public health and climate damage. If a DER offsets a generator that emits more damaging pollutants, it should receive a higher payment to reflect its environmental and public health value.

Any approach should take into account not only the generation displaced by a DER but also the emissions created by the distributed resource. For example, behind-the-meter DER generators include oil, gas/coal combined heating and power, and storage systems charged by fossil-fuel-fired generation resources. For emitting DERs, payment should be reduced based on their emissions and could potentially be negative if the negative impact of emissions from the DER is higher than the value of emissions avoided by that DER.

Key Terms

Emissions rate

The emissions rate is the amount of pollution emitted by a generator per unit of generation. If a generator emits 1 metric ton of SO₂ and generates 1 megawatt-hour (MWh) of electricity, then its emission rate of SO₂ is 1 metric ton/MWh, or 1 kilogram (kg)/kWh. The emissions rate can be affected by, among other things, installation of pollution control equipment, changes in the efficiency of the generator, or use of different fuels by generators that have fuel flexibility.

Damage per unit of avoided emissions

The damage per unit of avoided emissions is the monetized value of the harm that the pollution would have done had it been emitted. For instance, each kilogram of SO₂ released by a generator causes roughly \$50 of damage. Therefore, if a DER avoids the emission of one kilogram of SO₂ by displacing generation of a fossil fuel power plant, then it would avoid \$50 of damage.

Environmental value of displaced generation

The value of displaced generation is the dollar value of damages avoided, per unit of displaced generation. It is the product of the emissions rate and the damage per unit of avoided emissions.

Harnessing all the benefits DERs can provide requires compensating them for their environmental and public health value in a technology-neutral way that can take into account these different factors, while balancing accuracy and administrability. To achieve this goal, regulators must first identify the generation that is displaced by DERs, determine the emissions avoided by this displacement based on the emissions rates of the displaced resources, calculate the monetary damages per unit of avoided emissions, and then calculate the monetary value of the net damages avoided by DERs.

Below, we outline the necessary steps and then explain each step in detail.

Methodology Outline for Valuing the Environmental Benefits of DERs:

1. Identify the generation that is displaced by a DER
2. Calculate emissions rates (kg/kWh) of the displaced resource
3. Calculate the damage per unit (\$/kg) of avoided emissions
4. Monetize the value of avoided damage from displaced generation (\$/kWh)
5. Subtract any damages from the DER itself from the displaced generators' damages, to calculate *net* avoided damages

Step 1: Identify Displaced Generation

Distributed energy resources produce environmental and public health benefits by displacing generation from emitting power generators. The first step in calculating the value of those benefits, then, is to identify what generation will be displaced by a DER.

If sufficient grid operation and market information is available, it is possible to identify, with a reasonable degree of precision, the specific generator or generators that would have operated in the absence of DERs. If such data is not available, there are techniques that can be used to approximate which generators were displaced by DERs.

This section outlines three techniques for identifying displaced generation: (1) using counterfactual dispatch scenarios, (2) identifying the marginal generator, and (3) using electric market simulation models. These options are explained in order of decreasing levels of precision and decreasing information requirements.

All of these methodologies will identify those generators that have been displaced by DER resources *in the short run*. That is, these methodologies identify which of the *existing* resources would have generated in the absence of the DERs. They do not account for the potential effect that DERs have on the longer-term entry and exit incentives for emitting resources. Installation of DER capacity may contribute to the retirement of an existing fossil fuel-fired generator or may avoid the need for a new fossil fuel-fired generator. Therefore, methodologies presented in this section likely understate the extent to which DERs reduce emissions. Complex methodologies have been developed to account for these emissions effects; however, incorporating these effects into a DER valuation methodology is beyond the scope of this report.⁹

Running Counterfactual Dispatch Scenarios

Overview. It is possible for market operators to identify all of the generating resources that would have operated in the absence of DERs with precision and confidence. A market operator can run a counterfactual dispatch scenario in which the operator runs its regular dispatch algorithm while assuming no DERs. The generators that would have operated in this counterfactual dispatch scenario but were not actually dispatched are the generators that were displaced by DERs. These identified resources can be used in Steps 2-3 to calculate the avoided damages attributable to DERs.¹⁰

Advantages. The primary advantages of this approach are that it is accurate, granular, and flexible. Because it relies on actual grid operations and market data used to make dispatch decisions, this method can accurately capture which resources would have operated in the absence of DERs. Because this approach can identify the specific generators that have been displaced, it will also provide specific information on the location of displaced emissions, which is useful for calculating accurate public health damages in Step 3.

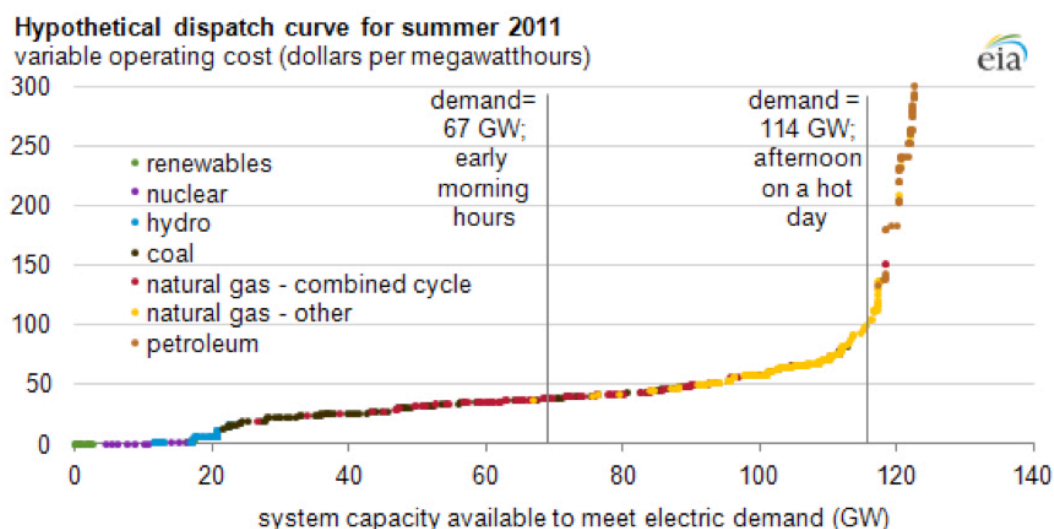
Counterfactual dispatch scenarios could be run as often as the grid operator reruns its dispatch algorithm. However, this approach is also flexible and can be updated less frequently if the administrative costs of frequently identifying counterfactual dispatch outweigh the benefits. For example, if there is limited variability in which resources are displaced over short intervals, grid operators could run counterfactual dispatch scenarios once per hour; during key parts of the day (such as during periods that typically have high electric demand and periods with low electric demand, or periods with high DER injections and periods with low DER injections); or during key times over each season of the year.

Limitations. The primary limitation of this approach is its significant data requirement. Regulators will have to work with distribution utilities to obtain the information—location, timing, and magnitude of DER penetration—needed for counterfactual dispatch scenarios, and then work with grid operators to produce counterfactual dispatch scenarios.

Identifying the Marginal Generator

Overview. An alternative approach to identifying displaced generation is to use information from the grid operators on marginal generators. Grid operators usually dispatch generators based on their cost of operation, as well as technical constraints of the system, until the total generation is high enough to meet the demand. The “marginal generator” for a given interval is the last generator that is needed to satisfy demand at that interval. Additional DERs at this time will reduce the need for generation from the marginal generator, and therefore avoid emissions from the marginal generator. States can work with grid operators to identify the generator on the margin at the time of DER operation, which can provide an accurate up-to-date estimate of which generators DERs are displacing.

Figure 2: Illustrative Market Supply Curve¹¹



Source: Energy Information Administration (2012)

Figure 2 is an illustrative market supply curve, which shows available generators in ascending order of marginal cost from left to right. Different levels of demand are illustrated by the vertical lines. The marginal generator for a given level of demand is the generator at the intersection of the vertical line and the supply curve. Based on this curve, when load is at its minimum, a gas generator with a relatively low bid will be on the margin. Any DER at this time will reduce the need for generation from that gas generator. When load is at its maximum, the marginal generator may be an oil-fired generator. DER will replace generation from the oil-fired generator.

Because the transmission system can be congested, the marginal generator will often be location dependent. If transmission lines are congested, electricity cannot be transmitted from distant locations even if there are available cheap generators, and therefore grid operators must rely on more expensive local resources. Take, for example, the New York Independent System Operator. When there is no congestion, a DER in New York City can indeed displace a system-wide marginal

generator, which can be located anywhere in the state. However, the transmission lines going in and out of New York City are often congested. During periods of such congestion near New York City, the marginal generator displaced by a DER in New York City will likely be local and different from the marginal generator displaced by a DER located in other parts of the state. States should therefore identify marginal generators at a level of geographic granularity appropriate given the level and location of congestion on the system.

If real-time information is not available from grid operators, regulators could identify marginal generators by matching load levels with generators on representative dispatch curves, such as the one outlined in Figure 2 above.¹² Such use of historical dispatch curves rather than actual dispatch curves for a given interval reduces the accuracy of this measure but it can be done with less involvement of the grid operator. These curves can be constructed using grid operator data, based on historical information on generator operation and energy bids. To most accurately reflect the generation mix available at a particular time, regulators should use historical dispatch curves applicable for times of day and seasons to reflect variations in renewable energy and seasonal outages.

Advantages. While identifying the marginal generator will require working with the grid operator, this approach requires significantly less involvement and data from the grid operator. This approach also will not require specific information from distribution utilities on the location, timing, and magnitude of DER load and generation profiles.

Limitations. This approach assumes that the magnitude of DERs is not large enough to change the marginal resource. Currently the level of DER penetration is small enough to meet this requirement in most contexts. In addition, especially during high-demand times when a small generator is on the margin, the next resource that would be marginal if that small generator is displaced may have quite similar emission characteristics. However, as DER penetration increases, it is possible that DERs will begin to change which generators are on the margin. This will reduce the accuracy of this approach as compared to the counterfactual dispatch scenario approach.

Electric Grid Dispatch Modeling

Overview. A number of sophisticated models of the electric grid have been developed that can be used to simulate the dispatch of generators under a variety of conditions.¹³ These models generally incorporate databases of generators (including the location, size, fuel type, and other operational characteristics) and transmission, assumptions about fuel and other operational costs of generation, and assumptions about electric demand to simulate operation of a given electric grid. Regulators can use these dispatch models to identify the resources that have been displaced by DERs, similar to how a grid operator would identify displaced generation through counterfactual dispatch scenarios. The electric model would be run both with and without DERs to identify the resources that have been displaced.

Regulators should perform model runs under a variety of assumed operating conditions (e.g., varying levels of electric demand, transmission congestion, and DER availability). They can then use the simulation that best matches the appropriate real-world circumstance.

Advantages. The primary advantage of this approach is that it can be used without involvement of the ISO/RTO or distribution utility. While the relevant models are complex and require expertise to use, Public Utility Commissions can develop this expertise rather than having to rely on outside entities for ongoing data requirements.

Limitations. Because these models rely on assumptions, rather than realized outcomes, they are not likely to be as accurate as the first two approaches outlined. In addition, this approach will be even less likely to incorporate any sectoral changes over time including generator entry and exit and generator outages, unless the model used is updated to reflect these changes.

An Approach to Avoid: Grid-Average Generators and Grid-Average Emissions rates

While there are many acceptable options to identify generators that will be displaced by DERs, regulators should *not* assume that DERs displace all generators in equal amount (either numerically or generation-weighted). Similarly, regulators should not use grid average emission factors when determining the avoided emissions attributable to DERs. Assuming DERs displace all resources equally or using *average* emissions rates will incorrectly include substantial zero-emission generators that are unlikely to be affected by DERs. Use of averages will also miss significant temporal and locational variation in the amount of air pollution displaced by DERs. Research has shown that using average emissions rates significantly misstates emission impacts of new resources.¹⁴ While this approach is computationally easy, and therefore appealing, using grid averages will not lead to accurate estimates.

Step 2: Identify Emissions Rates of the Displaced Generation

Once the resources that are displaced by DERs have been identified, the next step is to determine the emissions rates of those displaced resources. These emissions rates are necessary to determine the economic benefits of avoiding emissions from each kWh of the displaced emitting generation. Table 1 presents average emissions rates of select criteria and greenhouse gas pollutants by fuel burned.

Table 1: Average Emissions Rates of Select Pollutants for Generators in 2016¹⁵

Fuel Type	NO _x (kg/MWh)	SO ₂ (kg/MWh)	CO ₂ (kg/MWh)
Oil	2.92	2.86	862.80
Coal	0.75	1.08	1003.38
Biomass	1.58	0.67	211.06
Gas	0.16	0.00	405.94

Generator Features Affecting Emissions rates

Emissions rates are a function of (1) the type of fuel combusted, (2) the combustion and electric generation technology, (3) any pollution control equipment, and (4) environmental and operational considerations.

Fuel Type

The type and amount of pollutants emitted by electricity generators is primarily a function of the type of fuel used. Some plants are designed to burn only one type of fuel. Others, called “dual fuel” plants, are able to switch between fuels depending on fuel availability and price. Dual fuel plants generally can burn either natural gas or oil-based fuel (e.g., diesel fuel).

Uncontrolled combustion of coal, oil and wood biomass emits relatively large quantities of most criteria pollutants, HAPs, and greenhouse gases.¹⁶ Combustion of gas, including natural gas and landfill gas, primarily emits NO_x, CO, VOCs, and CO₂, with little to no direct emissions of PM, SO₂ and HAPs.¹⁷ On the other end of the spectrum, nuclear, hydroelectric, solar, and wind generation do not emit any air pollution.

Generation Technology

For a given fuel type, the primary determinant of the emissions rate is the efficiency by which a combustion technology converts fuel into electricity, called the generator’s “heat rate”.

Key Term

Heat rate is a measure of power plant efficiency. It is a measure of the amount of energy, embedded in the combusted fuel, measured in British Thermal Units, that it takes to generate a kWh of electricity.¹⁸ The higher the heat rate, the *less* efficient the plant.

Steam boilers generate electricity by combusting fuel to produce heat, which warms water to produce steam that turns an electric turbine. Steam boilers generally have high heat rates.¹⁹ In other words, they are not efficient. Steam boilers primarily use coal (and almost all coal plants use steam boilers), but they can also combust natural gas, fuel oil, or biomass.²⁰

Stationary internal combustion engines (ICE), which generally burn fuel oil, have similar heat rates to steam boilers and are most often used as “peaker plants” when demand is particularly high, for backup power, or as distributed generation.²¹

Combustion turbines use heat produced from fuel combustion to turn a turbine that generates electricity. They use liquid or gaseous fuel, including natural gas, fuel oil and biogenic fuels (e.g., landfill gas).²² Combustion turbines can range in efficiency and often function as peaker plants.

Finally, highly efficient combined-cycle plants combine the technologies to produce more electricity for the same amount of fuel.²³ In a combined-cycle plant, a combustion turbine produces electricity and heat, while the excess heat produces steam that generates more electricity. These plants primarily use natural gas (and much less often fuel oil).

Pollution Control Equipment

Emissions rates can also vary significantly depending on whether a plant has installed air pollution control technology. Almost all plants can implement some pollution control equipment, but there is significant variation in the type and effectiveness of installed equipment. For instance, flue gas desulfurization technology can reduce SO₂ concentrations of coal plant emissions by 98%, while catalytic reactions reduce NO_x pollution by 80%.²⁴ Pollution control equipment can also negatively affect the efficiency of power plants.²⁵

Operational and Environmental Considerations

A variety of environmental and operational considerations affect emissions rates. These include:

- **The age of the plant.** Plant efficiency generally declines with age.
- **The utilization of the plant.** Power plants that are operating below full capacity are generally less efficient and so have higher emissions rates.
- **Ambient weather conditions.** Ambient weather conditions including temperature, humidity, and pressure can affect the efficiency of a power plant.²⁶

These operational and environmental considerations vary over time, while other features like fuel type, generation technology, and pollution control equipment are relatively static. Therefore, it is not possible to know a particular

generator's emissions rate without measuring, in real time, its emissions and generation. Even though such data is rarely available, there are a number of existing or easy-to-develop tools that states can use to determine reasonably accurate emissions rates for generators.

Methods for Determining Emissions rates

States can use one of two primary options for determining reasonably accurate emissions rates: (1) historical, measured emissions rates of the generator, and (2) engineering estimates of a generator's emissions rates based on design characteristics and operational assumptions.

Historical Emissions Rates

Historical emissions rates calculate a given generator's emissions rate for each pollutant based on measured historical emissions and measured historical generation.

Historical Emissions. Generators above a specific size threshold are required to directly measure and report the volume of emissions for some pollutants to state environmental agencies and/or the U.S. EPA Clean Air Markets Division (CAMD). Continuous emission monitors are used to measure and report NO_x, SO₂, and CO₂ emissions from generators subject to certain federal environmental program requirements.²⁷ For pollutants where continuous emission measurement is not feasible or is particularly expensive (such as for PM), generators calculate and report emissions through monitoring of parameters that have a known relationship with emissions, such as operational characteristics of plant systems (temperature, pressure, liquid flow rate, pH), through periodic emissions testing, or based on quantities of fuel consumed and the technology used to generate electricity.²⁸

Historical Electric Generation. Generators are required to measure and regularly report various characteristics and operational performance of their plants to the U.S. Department of Energy's Energy Information Agency (EIA).

Dividing historic emissions by historic generation yields historic emissions rates. This calculation should be done with as high degree of granularity as possible in order to yield representative emissions rates for a generator's operational performance. For example, for a dual fuel generator, dividing annual total emissions of SO₂ by annual generation will not yield an accurate SO₂ emissions rate because SO₂ is only emitted in the hours that the generator burns fuel oil. Significant emissions rate changes for a generator can be captured by more daily or hourly emissions rate calculations.

Engineering Estimates

Engineering estimates of emissions rates are based on assumptions about known characteristics of generators. Accurate engineering estimates use the considerations identified above (fuel type, heat rate of generating technology, emission control technology, and environmental and operational considerations) to develop emissions rates that can be applied to generators with similar characteristics. Because of this, engineering estimates are sometimes referred to as "emission factors."

Selecting Between Historical Emissions and Engineering Estimates

Short of real-time continuous measurements, historical measured emissions rates are generally the best measure of a particular generator's emissions rate. Therefore, they should be used when available.

However, measured historical emissions rates are not always available for all sources. Existing databases are limited to those generators that exceed certain size and operational thresholds. Smaller generators, newer generators, or generators that did not operate over the historical period used to set emissions rates are not included in certain databases. In addition, because it is difficult to directly measure certain pollutants such as PM and air toxics, historical emissions rates for all pollutants may not be known for a given generator.

Finally, lack of temporal granularity of may produce misleading emissions rate estimates. In particular, the use yearly-average emissions rates may be problematic for generators that do not operate consistently over the course of a year, such as dual fuel peaking plants that may burn oil instead of natural gas when natural gas is unavailable or particularly expensive.

Where historical emissions rates are not available at all, or lack sufficient granularity, engineering estimates should be used.

Existing Tools and Databases

There are a number of existing databases that regulators can use to determine emissions rates. Different tools may be appropriate for different pollutants or for different desired levels of granularity.

This section outlines tools that fall into a number of categories: (1) Databases of generator-specific historical measured emissions; (2) databases of generator-specific historical measured generation, which, together, can be used by a state to develop generator-specific historical emissions rates; (3) databases of engineering estimates of emission factors; and (4) integrated databases that combine data from other sources to produce readily available emissions rates.

Table 2: Databases for Calculating Emission Rates

Tool	Data type	Pollutants covered	Covered sources	Data source	Update Frequency (last data year)
Historical Emissions Databases					
EPA CAMD	Generator-specific hourly emissions (can be aggregated)	NO _x , SO ₂ , CO ₂	Boilers > 25MW; combustion turbines, combined-cycle plants, & ICE online after 1990	Mandatory source-level reporting based on continuous monitoring	Monthly (Sept. 2017)
National Emissions Inventory	Unit-specific annual emissions	SO ₂ , NO _x , PM ₁₀ , PM _{2.5} , CO, VOC, NH ₃ , Hg, HCl	Power plants with criteria pollutant emissions over certain thresholds	State environment office reporting, supplemented by EPA CAMD data and emission factors	3 years (2014)
Historical Electric Generation Databases					
EIA Form 923	Unit-specific monthly electric generation and fuel consumption	n/a	Sources > 1 MW	Operator-level reporting	Monthly (Oct. 2017)
Engineering Estimate Databases					
EPA AP-42	Engineering-based estimates by fuel and technology type	SO ₂ , NO _x , PM ₁₀ , PM _{2.5} , CO, VOC, CO ₂ , CH ₄	Boilers, combustion turbines, and ICE using coal, natural gas, fuel oil, and biomass	EPA tests of representative technology	Infrequent (1998-2008)
National Energy Technology Lab	Engineering estimates	CO ₂ , SO ₂	Modern highly-efficient natural gas combined-cycle plants	Department of Energy engineering analysis of modern plants	Infrequent (2010)
Integrated Databases					
eGrid	Unit-specific annual emissions and electric generation	NO _x , SO ₂ , CO ₂	Electric generating units that report electric generation data on EIA-923	Emissions: EPA CAMD and AP-42 Generation: EIA-923	Sporadic, generally 1-4 years (2016)
Argonne National Labs GREET	Attribute-based emission factors using statistical analysis of historic emissions rates and open literature review	CO ₂ , CH ₄ , NO _x , SO ₂ , CO, VOC, PM ₁₀ , PM _{2.5}	Boilers, combustion turbines, combined-cycle plants, ICE burning coal, nat. gas, fuel oil, and biomass, with various pollution control equip.	EPA eGRID, AP-42, open literature	Sporadic (2012 for full update, 2017 for limited update)

Generator-Specific Historical Emissions Databases

EPA maintains a number of databases of power plant emissions. However, no single database contains information on all important pollutants. Combining datasets is necessary to get a full picture of generator emissions.

EPA Clean Air Markets Division

Overview. EPA's CAMD collects emission data from large air pollution sources, including power plants, in order to administer a number of federal environmental programs. Electric generators subject to reporting requirements include steam generators with at least 25 MW capacity, non-steam generators – gas turbines, combined cycles, internal combustion engines – that came on-line after 1990, and independent power producers/co-generators that sell over a specific amount of electricity.²⁹ These generators report hourly emissions of NO_x, SO₂, and CO₂, collected from CEMs, to EPA on a quarterly basis. The hourly data can then be aggregated into daily, monthly, or seasonal data.

Advantages. Using hourly emission data would allow state utility regulators to calculate emissions rates that take into account environmental and operational characteristics. Because the data is collected from continuous monitoring, it is also more accurate than data collected through other means.

Limitations. The biggest limitation is that CAMD does not include historical data on a number of key pollutants, such as PM. CAMD only recently began collecting data on mercury, hydrogen chloride, from some coal and oil-fired steam generators.³⁰

National Emissions Inventory

Overview. The National Emission Inventory (NEI) is a database of annual emissions for a wide variety of sources, including power plants with a potential to emit criteria pollutants above a 100 tons per year threshold.³¹ NEI data includes generator-specific emissions of PM₁₀, PM_{2.5}, VOCs, CO, HAPs, SO₂ and NO_x emissions.³² Data is based primarily on data reported to EPA from state environmental agencies, supplemented and modified by data that EPA itself collects and other EPA assumptions.³³ New data is collected by EPA every three years, and released three years later after it goes through a substantial quality assurance process. The 2014 National Emissions Inventory was released in 2017.

Advantages. The primary advantage of NEI data is that it contains emissions of a wider variety of air pollutants than CAMD, including PM.

Limitations. Infrequent updating is the primary limitation of the NEI. The NEI is updated only every 3 years, on a 3-year delay. Therefore, accurate emissions rates will not be available for sources built or substantially modified after 2014. In addition, NEI contains only annual (and for NO_x, summer season) emissions.³⁴ Therefore, emissions rates calculated using this data source will be limited to annual average emissions rates (and, for NO_x, ozone season average emissions rates), and will have limited accuracy for plants whose emissions rates vary with operational changes, such as mid-year changes in fuel used.

Generator-Specific Historical Generation Databases

EIA-923

Overview. Operators of electric generators greater than 1 MW report net electric generation (as well as fuel consumption) to the Department of Energy's Energy Information Agency (EIA) on form EIA-923.³⁵ All generators report generation annually, and a large subset report generation on a monthly basis.³⁶ For generators that are not included as part of the sample, EIA imputes monthly generation data using statistical techniques.³⁷

Advantages. EIA data is readily accessible online and practitioners consider it as the best source of widely available generation data.

Limitations. Emissions rates more granular than monthly averages are not available.

Engineering Estimate Databases

EPA AP-42

Overview: EPA has developed *AP-42 Compilation of Air Pollution Emission Factors* for a wide variety of pollutants and source categories. These factors are often used by EPA when measured data is not available and can be used by states to develop assumed emissions rates for sources where EPA data is not available.³⁸

AP-42 provides emission factors for the following combustion technologies: steam boilers;³⁹ stationary combustion turbines;⁴⁰ and large stationary diesel and dual-fuel engines.⁴¹ It generally includes emission factors for criteria pollutants and their precursors, HAPs, and greenhouse gases (including CO₂ and methane).

Advantages. AP-42 provides a standard set of widely used emissions factors. It is therefore easy to use when historical emissions data is not available.

Limitations. AP-42 emission factors have not been updated since the late 1990s and early 2000s. This is particularly an issue for generation technology that has seen significant advancements since the last AP-42 update, including natural gas combined-cycle combustion technology. In addition, recent analysis has shown that the factors do not capture the wide variety of emissions rates from actual facilities.⁴²

NETL Natural Gas Combined-Cycle Analysis.

Overview: In 2010, the Department of Energy's National Energy Technology Laboratory (NETL) evaluated the cost and performance of representative fossil fuel-fired power plants, including new NGCC power plants. As part of this report, NETL developed air pollution emissions rate estimates for a standard NGCC plant.⁴³ These emission factors have been used by academic researchers studying the economic costs of air pollution externalities from power plants.⁴⁴ For relatively modern, large NGCC plants, states could use generic emissions rates based on this research.

Advantages. Up-to-date and widely used emission factors for modern NGCC technology.

Limitations. Limited to emission factors for a single generation technology type.

Integrated Emissions and Generation Database

There are two integrated databases that combine available emissions and generation data from the databases outlined above and other sources. These databases can help determine emissions rates with minimal additional work by utility regulators.

EPA eGrid Database

Overview. EPA maintains the eGrid database⁴⁵, which contains annual average emissions data and annual average generation data for most electric generators, compiled from a variety of data sources. The primary source for generation data is EIA form 923.⁴⁶ The primary source of EPA's emission data is EPA CAMD.⁴⁷ For generators that do not report to CAMD, EPA calculates annual emissions by multiplying emissions factors from AP-42 by the plant's heat rate (as reported to EIA).⁴⁸

Advantages. The primary advantage of eGrid is that EPA has already done the work to compile and validate relevant data from CAMD, AP-42, and EIA.

Limitations. eGrid does not include data on key pollutants, such as PM and air toxics. Because eGrid provides *annual* emissions and generation data,⁴⁹ eGrid data does not take into account emissions rate changes that could result from variation in the fuel used by a plant throughout the course of a year, changes in capacity factor, or other operational and environmental characteristics.

Argonne National Laboratory GREET Emission Factor Database

Overview. Argonne National Laboratory (ANL) has developed a model for estimating lifecycle greenhouse gas and criteria pollutant emissions associated with various vehicle technologies: the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model.⁵⁰ In order to estimate lifecycle emissions of electric vehicles with this model, ANL has compiled a database of power sector emission factors broken out by relevant attributes such as fuel type, generation technology, and pollution control equipment.⁵¹ The GREET emission factor database was developed using data from CAMD, EIA, AP-42 and the open literature.

Advantages. The GREET emission factor database includes emission factors for a wide variety of pollutants, including those not included in eGrid, such as PM_{2.5}. The database is broken out by many generator characteristics, so more accurate emissions rates can be identified, so long as relevant attributes of a given generator are known. It is updated more frequently than AP-42 (the last comprehensive update was in 2012, but limited updates were made in 2013 and 2017).⁵² ANL conducted robust statistical analysis to arrive at emission factors.

Limitations. The GREET emission factor database includes general attribute-based emissions rates. Therefore, it is not as accurate as historical emissions rates for specific generators when such rates are available.

Estimating Displaced Emissions if Step 1 is Not Feasible

The methodologies described in Steps 1 and 2 of this report identify the emissions avoided by a DER by identifying specific generators that would be displaced and determining the emissions rate of those generators. However, when it is not possible to identify specific generators due to lack of data, it is possible to estimate the emissions displaced by DER by using econometric techniques.

Academic researchers have been using regression analysis to directly estimate the grid's marginal emissions rates.⁵³ This method requires high-frequency data on emissions of the pollutant of interest and the quantity of electricity demand – the load – for a particular electric grid. A linear regression of emissions on load will yield the relationship between changes in measured emissions from all generators on the grid and changes in electricity demand. The marginal emissions rates at a given time and location can then be estimated based on the level of electricity demand at that location and time.

The granularity of this method depends on the granularity of the underlying data. For example, if data are available on zonal level emissions and load, then marginal emissions can be calculated to the zonal level for each season or time of day.

Limitations: Because marginal emissions rates are estimated for a given area, assumptions are required about where specifically emissions will occur. This will limit the accuracy of damage estimates outlined in Steps 3-4 below. In addition, this approach will not be responsive to changes in the electric sector such as short-run changes caused by generator outages and medium-run changes in the composition of generators over time. Therefore, this approach should be used only to the extent that utility regulators are not able to obtain information from grid operators and cannot use electric market models.

Step 3: Calculate the Monetary Damages from Emissions

Air pollutants cause damage to human health, impair ecosystems, and harm crops and other production activities. The goal of this step is to find the monetary value of the damages from each unit of emissions identified in the previous step. Given knowledge of the emissions rate for a power generator, regulators can calculate damages as a function of the pollutants being emitted, the location where those emissions occur, the time of day and year when they occur, and ambient environmental conditions like weather and pollution concentrations. The most accurate calculation of damages would incorporate each of these elements.

Relevant Factors for Calculating Monetary Damages

The sections below discuss the factors needed for calculating monetary damages from emissions, as well as the motivation for incorporating these different elements and the key issues related to granularity versus ease of administration.

Pollutants Emitted

The previous section identified a number of pollutants emitted by fossil power generators. Each pollutant has its own relationship between exposure and impact, called the *dose-response function* or *damage function* in epidemiological and economic research. These different damage functions should be accounted for when calculating damage per unit of emissions for accurate assessment of the value of avoided emissions.

Toxic Heavy Metals

Toxic heavy metals like mercury or lead cause rapid health deterioration even for low concentrations and quickly become fatal. Heavy metals like mercury and lead can also decrease brain function, leading to marked reduction in IQ.⁵⁴ The harms also occur over long periods of time because heavy metals do not break down once they are released, leading to long-run harms as the public is exposed the pollutant over long periods of time and permanent, negative health effects for individuals whose bodies cannot get rid of the toxins. Because the harm caused by these metals is so extreme, the damage per unit of emissions is correspondingly high.⁵⁵

Sulfur Dioxide (SO₂)

Sulfur dioxide (SO₂) is a gas released during combustion of oil and coal that negatively affects the environment and human health. SO₂ irritates mucous membranes in the lungs, eyes, nose, and throat, exacerbating conditions like asthma.⁵⁶ SO₂ also breaks down into particulate matter. Fine particulates, especially those smaller than 2.5 micrometers, called PM_{2.5}, penetrate into the lungs, causing or exacerbating cardiovascular problems like asthma and heart disease. Fine particulate matter is also a primary contributor to haze and visibility reduction in much of the United States.⁵⁷ SO₂ is also a major contributor to acid rain.⁵⁸

Nitrogen Oxides (NO_x)

Nitrogen oxides are gases including nitrogen dioxide, nitrous acid, and nitric acid. Collectively, these gases are referred to as NO_x.⁵⁹ Like SO₂, NO_x breaks down into particulate matter, causing cardiovascular health effects and contributing to haze.⁶⁰ NO_x, along with other pollutants like VOCs, react with sunlight to create ozone pollution, which is a respiratory irritant that aggravates conditions like asthma.⁶¹

Greenhouse Gases

Greenhouse gases, including carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O), lead to climate change.⁶² Greenhouse gases exert a warming effect on the global climate. This warming is already having noticeable, damaging effects on the environment and the economy.⁶³ These damages are expected to increase in the future as further climate change occurs.⁶⁴

Ambient Concentration

Ambient pollution concentrations affect the amount of damage that results from additional pollution emissions. Some pollutants cause severe health effects at low concentrations, so even small emissions of such pollutants can be dangerous, depending on ambient levels. One such pollutant is mercury. Even small concentrations of mercury can cause mortality, so an increase in emissions of mercury in an area with a high pre-existing concentration can cause severe health effects.⁶⁵ In contrast, an increase in emissions of a pollutant like particulate matter will cause declining marginal damage as the ambient concentration rises.⁶⁶

Pollutants can also interact, exacerbating effects. For instance, ozone creation is more likely in the presence of both VOCs and NO_x.⁶⁷ Pollutant interaction makes it potentially important to account for ambient concentration of other pollutants when calculating damages per unit of emissions. Such interaction effects might be challenging to quantify in a way that is also easy to administer, so a reasonable alternative would be to incorporate damages that vary by location depending on the average or usual concentration of important ambient pollutants.

Pollution Transport

Pollution can be carried away from the area where it is created through a process called pollution transport. Wind and water carry pollutants away from the point of emission, potentially exposing populations far from the emission source.⁶⁸ Rain washes particulate matter out of the air and into bodies of water.⁶⁹ Pollution transport models are useful for understanding this movement of pollutants from source to final location. For instance, lighter pollutants like fine particulates can be carried farther than heavier pollutants like PM₁₀, making modelling of transport for fine particulates relatively more important for correct damage estimation.⁷⁰

Secondary Pollutants

Related to pollution transport, pollutants break down and potentially create other, secondary pollutants as they travel through the atmosphere. As discussed above, SO₂ and NO_x break down to create particulate matter. Ozone forms when sunlight reacts with oxides and organic compounds in the air.⁷¹ Thus, ozone is less likely to form at night and is also less likely to form in the winter, making time of day and year important for damage from this pollutant.⁷²

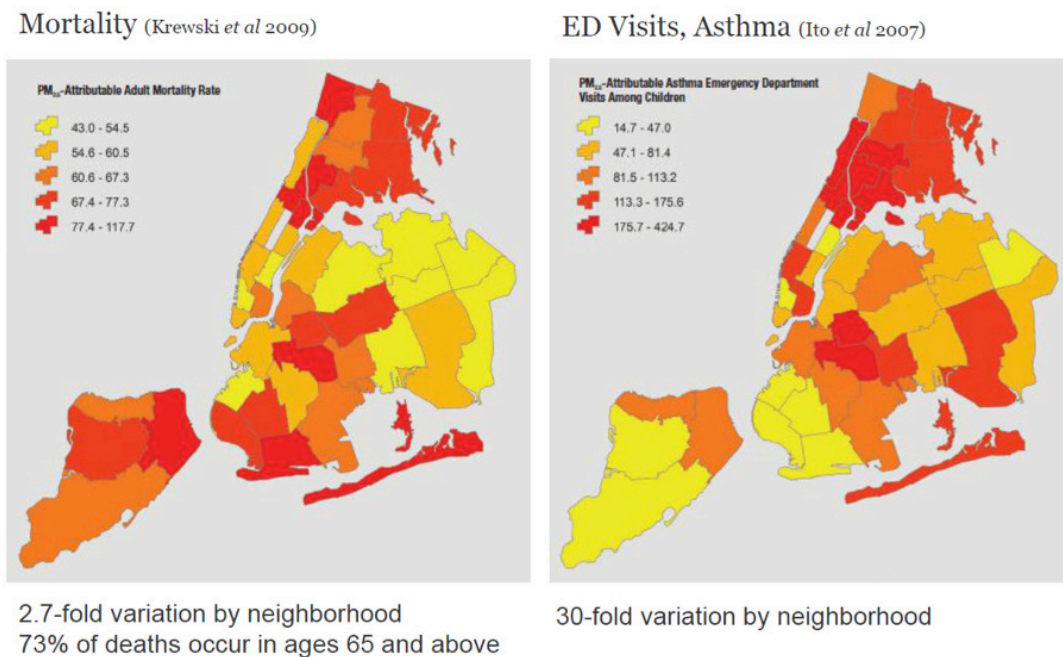
Exposed Population

Pollution causes damage when individuals are exposed to that pollution, so the size of the exposed population is one of the most important drivers of changes in damage from pollution. Densely populated areas experience more damage from a given amount of pollution simply because more people are exposed to that pollution. For instance, $PM_{2.5}$ released in the eastern region of the United States causes between \$130,000 and \$320,000 in damages per ton according to EPA estimates. A ton of $PM_{2.5}$ emitted in the western part of the United States, however, causes \$24,000 to \$60,000 in damage.⁷³ The difference in these estimates is primarily attributable to differences in population density.

Population Health

The healthiness of the exposed population also affects damage. Ozone created in an area with high asthma rates will cause more health damage than ozone released in an area with very few asthma sufferers. Overall health affects the vulnerability of individuals to mortality from pollutants. For example, Figure 3 shows that in New York City, $PM_{2.5}$ -attributable mortality rate is higher in portions of Brooklyn than in southern Manhattan.⁷⁴

Figure 3⁷⁵



Source: NYC Department of Health and Mental Hygiene Bureau of Environmental Surveillance and Policy (2013).

The left panel shows the relationship between $PM_{2.5}$ and adult mortality for neighborhoods in New York City. The same quantity of $PM_{2.5}$ causes about twice as much mortality in a neighborhood colored red versus yellow. The right panel shows the relationship between $PM_{2.5}$ and child emergency room visits for asthma in New York neighborhoods. For asthma, the same quantity of $PM_{2.5}$ causes about ten times more emergency room visits in a neighborhood colored red versus yellow. Both panels show that the damage from air pollution usually depends on local characteristics like population health.

Methodologies for Calculating the Damage per Unit of Emissions for Pollutants that Depend on Time and Location

Accounting for all of the factors that affect damages using custom models would lead to the most accurate calculations of damage per unit of emissions. However, data constraints and ease of use might make alternative, less granular methods more desirable. Table 1 shows examples of different damage calculation methods that tradeoff between these two goals of accuracy and administrability. The most granular methods use high-resolution population data with time-varying pollution transport models. Less granular methods make stronger assumptions or use more aggregated data to reduce the complexity of calculation.

Custom Solutions

On the most granular side, policymakers could build a custom model that takes into account as many factors affecting damage per unit of emissions as possible. A recent example of such an approach is the Bay Area Clean Air Plan.⁷⁶ The Bay Area Air Quality Management District created a custom tool that translates emissions of multiple different pollutants into changes in pollution concentration throughout the Bay Area. The tool uses weather data to understand how pollutants are transported around the Bay Area, and it uses atmospheric chemistry models to understand how different primary pollutants cause secondary pollutants in the region. For instance, ozone is created by a complex interaction between different pollutants and sunlight, so the atmospheric chemistry models are important to understanding how ozone pollution can be addressed.

The model then uses population density to translate pollution concentration changes into human exposure. The exposure determines health effects according to the pollutant being considered and the health conditions of the exposed population.⁷⁷ The Bay Area Air Quality Management District focuses on PM, ozone, and greenhouse gas pollution, but in principle, any pollutants could be incorporated into a similar methodology.

One of the primary benefits of a custom method is the ability to incorporate variation in population density and population health. This ability is especially important for states that are characterized by a high degree of heterogeneity in population density. Pollutants emitted in areas near big urban cities would cause substantially higher exposure than the same pollutant emitted in more sparsely populated rural regions. This effect might be exacerbated if higher-emission power plants are located in the higher-population areas, leading to higher ambient pollution levels.⁷⁸ This correlated heterogeneity means that policymakers should avoid an approach that uses a state-wide average damage per unit of emissions, since such an approach would vastly understate damages in some areas of the state while overstating damages in others.

Estimating Air Pollution Social Impact Using Regression

Estimating Air Pollution Social Impact Using Regression (EASIUR) is a model of the damages from emission of primary PM_{2.5}, SO₂, NO_x, and NH₃. The damage estimates are based on mortality due to secondary particulate matter.⁷⁹ One of the primary benefits of EASIUR is easy-to-use but accurate modeling of pollution transport. EASIUR was created by taking high-resolution, detailed pollution transport model output from the Comprehensive Air Quality Model with Extensions (CAMx)⁸⁰ to derive simple estimates of pollution transport on a 36 by 36-kilometer grid for the United States.⁸¹ As a result, EASIUR provides relatively accurate estimates of air pollution damage based on the location of

emissions without the cost of complex and time-consuming modeling of detailed pollution transport. EASIUR also provides estimates of damages for three different stack heights—ground level, 150m, and 300m.

BenMAP

BenMAP is a tool created by EPA to calculate and map damages from ozone and $PM_{2.5}$ in the United States. BenMAP does not include pollution transport modeling. Users specify the change in ambient concentration of pollution that they expect will occur due to a policy, and BenMAP monetizes the health impacts of that change based on population density and pollution damage functions derived from academic publications. It includes high-resolution population data (a 12 by 12-kilometer grid) and can be customized with user-defined population data, baseline health data, and pollution damage functions.⁸²

Air Pollution Emission Experiments and Policy Analysis Model

Air Pollution Emission Experiments and Policy analysis models county-by-county marginal damage estimates for SO_2 , NO_x , $PM_{2.5}$, PM_{10} , NH_3 , VOCs. This model allows specification of stack height. This is important in locations like New York City, where the combination of low stacks and large population combine to create high marginal damages for peak generators that often have relatively high emissions rates.⁸³

Co-Benefits Risk Assessment

The Co-Benefits Risk Assessment (COBRA) tool from EPA uses a simple pollution source-receptor matrix and a subset of the BenMAP health damage functions to estimate county-level damages from the creation of secondary $PM_{2.5}$ from emissions of NO_x , SO_2 , NH_3 , $PM_{2.5}$, and VOCs. Like BenMAP, COBRA can be modified with custom population, baseline health, and baseline emission data as well as custom damage functions. COBRA damages are based on mortality and morbidity due to nonfatal heart attacks and cardiovascular illness.⁸⁴

Table 3: Tools to Calculate Damage per Unit of Emissions

Tool	Geographic Granularity	Additional Data Requirement	Pollutants Covered	Notes	Source
Custom model	Variable	High	ozone (NO _x ,VOC), PM _{2.5} (directly emitted PM _{2.5} , NO _x , VOC, SO ₂), air toxics	Geographic-specific damage estimates based on: <ul style="list-style-type: none"> • Air transport • Ambient concentrations • Population • Comorbidity 	Bay Area Air Quality Management District Multi-Pollutant Evaluation Method (2017)
BenMAP	High (default); Variable (custom)	Medium (default); Varies (custom)	ozone, PM _{2.5}	<ul style="list-style-type: none"> • Translates all pollutants into secondary PM & ozone • Driven primarily by mortality • Can input own data 	U.S. EPA
EASIUR	36 km	Low	SO ₂ , NO _x , NH ₃ , PM _{2.5}	<ul style="list-style-type: none"> • Detailed air transport model • Seasonal damages 	Heo, Adams, and Gao (2016)
AP2	County	Low	SO ₂ , NO _x , VOC, NH ₃ , PM _{2.5} , PM ₁₀	<ul style="list-style-type: none"> • Accounts for air transport • Broader monetized damage categories 	Muller, Mendelsohn, Nordhaus (2011)
COBRA	State or county	Low	PM _{2.5} (directly emitted PM _{2.5} , NO _x , VOC, SO ₂)	<ul style="list-style-type: none"> • Recently updated (2017) • Previously used by NY PSC • Accounts for air transport • Driven primarily by mortality 	U.S. EPA (2017)

Greenhouse Gases – Methodology for Calculating Damage per Unit of Emissions

Damages from greenhouse gases do not depend on the time or location of release, making the calculation of their damage per unit of emissions particularly straightforward.⁸⁵ The Interagency Working Group's Social Cost of Carbon is the best estimate of the damages caused by greenhouse gas emissions.⁸⁶

The Social Cost of Carbon is the net-present value of damage caused by the emission of one metric ton of carbon dioxide today. The emissions of greenhouse gases like methane and nitrous oxide from electricity generation can be translated

into carbon dioxide-equivalent units using methodologies developed by EPA.⁸⁷ The Social Cost of Carbon can then be used to calculate the damage per unit of emissions of all greenhouse gases.

The Interagency Working Group first developed the Social Cost of Carbon in 2010 and updated the estimate in 2013 and 2015.⁸⁸ In 2016 and 2017, the National Academies of Sciences issued two reports that recommended future improvements to the methodology.⁸⁹ In response to those reports, researchers at Resources for the Future and the Climate Impact Lab are working on further updates.⁹⁰

The Interagency Working Group's estimate has been repeatedly endorsed by government reviewers, courts, and experts. In 2014, the U.S. Government Accountability Office reviewed the Interagency Working Group's methodology and concluded that it had followed a "consensus-based" approach, relied on peer-reviewed academic literature, disclosed relevant limitations, and adequately planned to incorporate new information through public comments and updated research.⁹¹ In 2016, the U.S. Court of Appeals for the Seventh Circuit held that relying on the Interagency Working Group's estimate was reasonable.⁹² And though the current Administration recently withdrew the Interagency Working Group's technical support documents,⁹³ experts continue to recommend that agencies rely on the Interagency Working Group's Social Cost of Carbon estimate as the best estimate for the external cost of greenhouse gases.⁹⁴

Step 4: Monetize the Avoided Externality from Displaced Generation

Once the displaced resource has been identified and both the emissions rates and the damage per unit of emissions are known, these two values can be multiplied to get the monetary value of avoided damages per unit of generation.

If other existing policies already internalize externalities, such as a cap-and-trade program, an additional step to take these policies into account is necessary. Failing to take these policies into account could lead to double counting of the benefits generated by pollution reduction. To see this, consider a case where bulk system generators are subject to a policy that requires payment per ton of CO₂ emitted. The cost of operation for such emitting generators will be higher, and therefore they would submit higher bids to the wholesale electricity market. These higher bids would result in a higher equilibrium price in the market, so any resource that did not emit CO₂ (or emitted less CO₂ than the marginal resource) would receive the benefit of this higher price. In this way, zero or low emitting resources—like a clean DER—would be incentivized to produce more, and high emitting resources would be incentivized to either reduce their emissions or to produce less. If DERs also received direct payments for the full environmental and public health externality of emissions on top of this price increase, the result would be double payment for the same benefits.

If the existing policies do not fully internalize the externality from pollution, then DERs should receive payment that is sufficient to achieve full internalization. States participating in the Regional Greenhouse Gas Initiative (RGGI), a cap-and-trade program run by nine states in the Northeast, provide a good example. Generators in these states that are larger than 25 megawatts must pay for emissions of CO₂ by purchasing emissions permits under RGGI.⁹⁵ If the generator displaced by a DER is a participant in RGGI, then the price in the wholesale market already incorporates a payment for CO₂ emissions, and the monetized value of avoided emissions should take that into account. Current and forecasted RGGI permit prices, however, are not sufficient to fully internalize the external damage from CO₂, so clean DERs should still receive a payment for CO₂ emissions that they avoid. The payment should be reduced to reflect the degree to which the CO₂ externality has been internalized by RGGI.

Numerically, consider a case where the displaced resource is a combined-cycle natural gas plant that emits one ton of CO₂ per MWh of generation.⁹⁶ If there were no policies that required the displaced generator to pay for carbon emissions, then the value of avoided damages from each kWh injection would be the emissions rate times the external damage per unit of emissions. The external damage caused by carbon dioxide, as discussed in the previous section, is given by the Social Cost of Carbon and the central estimate is currently around \$46 per metric ton in 2017 dollars.⁹⁷

$$\text{External value of avoided CO}_2 = 1 \frac{\text{kg CO}_2}{\text{kWh}} \times 0.046 \frac{\$}{\text{kg CO}_2 e} = 0.046 \frac{\$}{\text{kWh}}$$

Therefore, for every kWh of displaced generation, a zero-emitting DER would provide a benefit of roughly 5 cents by internalizing the externality from CO₂ emissions.

The payment for a concurrently existing cap-and-trade policy such as RGGI changes this calculation. The current RGGI price is around \$4 per metric ton of CO₂. If the displaced generator is paying for RGGI permits, then \$4 of the external cost of CO₂ has already been internalized, meaning that the uninternalized damage from CO₂ is \$46–\$4=\$42. The value of avoided damage from CO₂ in this case would be:

$$\text{External value of avoided CO}_2 \text{ with RGGI} = 1 \frac{\text{kg CO}_2}{\text{kWh}} \times (0.046 - 0.004) \frac{\$}{\text{kg CO}_2} = 0.042 \frac{\$}{\text{kWh}}$$

The value of avoided external damage falls to reflect the fact that some of the external damage from carbon has already been internalized.

As another example, consider an alternative policy that is being discussed in several jurisdictions: carbon pricing. If a carbon charge is levied on electricity sold in a state, the charge would raise the price that wholesale electricity generators pay for carbon emissions and hence help internalize the externality. If this charge is based on the Social Cost of Carbon, then the external value of avoided emissions of CO₂ would fall to zero since the externality would be fully internalized.

$$\text{External value of avoided CO}_2 \text{ with charge} = 1 \frac{\text{kg CO}_2}{\text{kWh}} \times (0.046 - 0.046) \frac{\$}{\text{kg CO}_2} = 0.00 \frac{\$}{\text{kWh}}$$

In practice, the benefits from implementing a carbon charge in the state would come from both the incentive it would provide to clean generation and the disincentive to emitting generation, leading to a higher likelihood of the displaced generator having a lower emissions rate as well.

When setting the level of payment for other pollutants, policies including the Cross-State Air Pollution Rule (CSAPR) for NO_x and SO₂, the Mercury Air Toxics Standard (MATS), and other future policies should also be taken into account. In the case of a policy like the RGGI cap-and-trade program, discussed above, a positive permit price that results from a binding cap should be taken into account by reducing the payment to DERs in proportion to the amount of the environmental and public health externality that has been internalized. For other programs, like CSAPR, where the cap is currently not binding and the permit price has settled near \$0, no adjustment needs to be made.⁹⁸ If the cap binds in the future and prices rise above zero, then the payment to DERs would need to be adjusted.

The table below summarizes recent values of the damage per unit of generation from three different analyses done by different state and federal agencies. As the table shows, these different agencies come to similar conclusions regarding the value of avoiding these different pollutants.

Table 3: Examples of Dollar Value of Average Damage per MWh⁹⁹

Pollutant	2016 EPA RIA	New York DPS	Bay Area Clean Air Plan
SO ₂	\$76 to \$171 per MWh	\$52 to \$55 per MWh	\$77 per MWh
NO _x	\$4 to \$12 per MWh	\$5 per MWh	\$3 per MWh
PM _{2.5}	\$7 to \$16 per MWh		\$22per MWh

Step 5: Monetize and Subtract DER Damages

The final step is to take into account any emissions generated by the DER itself. Distributed energy can come from non-emitting resources like solar panels or small wind turbines or it can come from emitting resources like combined heating and power generators, diesel generators, or small natural gas fuel cells. In fact, the Department of Energy estimates that the majority of DERs in the United States are emitting backup generators, and that in 2006, 42% of DER energy produced in the country came from combined heating and power.¹⁰⁰ If the DER emits pollutants, then those emissions and the damage they cause must be taken into account to accurately quantify the environmental and public health values of the resource. Damages from energy storage systems that are charged by emitting resources should be calculated similarly. In this case, damages from the DER's own emissions must be calculated and netted out from the value of emissions avoided by the DER. In cases where the DER does not emit, this additional step is not necessary, and the calculation of environmental value is simply the external value of avoided emissions calculated in the previous step.

Step 5A: Monetize the Externality from DER

If the DER emits pollutants, then the externality associated with emission of those pollutants must be accounted for, in the same way that the value of emissions from displaced generation was calculated in Steps 2, 3, and 4. First, policymakers need to know the DER's emissions rate for each pollutant. Lack of data on emissions rates presents a unique challenge for calculating damages from DERs. Resources like eGrid and the National Emissions Inventory do not record emissions or generation for very small generators. Instead, policymakers will likely need to rely on engineering estimates of emissions rates. As an alternative, policymakers could also use EPA emissions standards for non-road generators to estimate emissions.¹⁰¹ Note that fossil-fuel-burning DERs generally produce higher emissions per unit of generation than otherwise comparable, large generators because the latter benefit from returns to scale in generator efficiency.¹⁰²

Second, the policymaker must determine the damage per unit of emissions given the DER's location, time, and pollutants emitted. Damages per unit of emissions from DERs will also likely be different than from a similarly located large generator given that large generators generally have tall stacks that allow pollutants to disperse their over a larger area. Moreover, since DERs are generally located near load centers, they are also generally located nearer to areas of relatively high population density.¹⁰³ Proximity to higher population will raise the damage per unit of emissions from emitting DERs.

Using these numbers, the value of damage per unit of electricity generation can be calculated for the DER in the same way that the value is calculated for larger generators. In particular, the value per unit of generation will be the sum across all pollutants of the emissions rate times the damage per unit of emissions.

Step 5B: Subtract the Value of DER Emissions from the Value of Avoided Emissions

The last step for finding the environmental and public health value of DERs is to subtract the value of emissions from the DER calculated in Step 5A from the value of avoided emissions calculated in Step 4. Subtracting these two values must be the last step of the process. In other words, the dollar value of damages per unit of generation from the two resources

should be calculated first, then the value of damage from the DER should be subtracted from the value of damage from the displaced resource. This procedure will correctly estimate the net environmental value of the DER by including differences in emissions rates and damage per unit of emissions discussed above. Incorrect calculations would net out either generation or emission before calculating the damages. Netting out generation first would not account for unique emissions by the two resources. Netting out emissions first would not account for the differences in location and exposed population between the two resources.

For instance, consider a case where the DER emits pollution in a high population area while the displaced resource would have emitted pollution in an area with lower population. The damage per unit of emissions is higher from the DER, but if the emissions are first subtracted from each other, then this difference between the two resources would be lost. In such a case, the DER would be erroneously incentivized to produce more electricity, increasing the damage experienced by the high population area.

If damage per unit of generation from the DER is high enough, then the net environmental value of the DER could be negative. This might be the case, for instance, if a diesel generator located in close proximity to a high-population area is displacing generation from a relatively clean natural gas plant located further from a populated area.¹⁰⁴ In these cases where the DER causes more environmental damage than it avoids, it should be penalized for that damage. In other words, the “compensation” for the environmental and public health value may be negative. Failing to do so would also fail to fully internalize the environmental externality associated with emissions.

Example Calculation

To illustrate the calculation of the value of DER using all of the above steps, consider an example of DERs in New York State. New York's current generation mix primarily includes hydropower, nuclear, natural gas, oil, and renewables.¹⁰⁵ Figure 2 shows a representative dispatch curve for New York. During periods of low electricity demand, a DER might offset hydro or nuclear generators, resulting in no avoided emissions. During these periods, the environmental and health value paid to the DER would be zero for a zero-emitting DER and would be negative for any DER like a diesel generator that produces emissions.

During periods with near-average load, the marginal fuel is natural gas. Typical natural gas generators in New York emit relatively low levels of NOx and PM, and moderate levels of CO₂. They do not emit SO₂. As demand rises during periods of particularly high load, oil becomes the marginal fuel and the emissions per unit of generation rise. Currently, New York does not produce any power from coal. A small amount of biomass production occurs in the state, but biomass has, historically, not been the marginal fuel in any region of the state.¹⁰⁶ During the course of a single day, the marginal generator might change from zero-emitting nuclear, to gas, and to oil and back again as load shifts. Table 4 summarizes the emissions rates for typical gas and oil generators in the state. These emissions rates provide the necessary data for Step 2 of the method described above.

Table 4: Average Emissions Rates for Fossil Fuel Generators in New York¹⁰⁷

Fuel Type	SO ₂ (kg/MWh)	NOx (kg/MWh)	CO ₂ (kg/MWh)	PM _{2.5} (kg/MWh)
Oil	2.10	2.62	1059.3	0.35
Biomass	0.16	2.71	481.7	0.02
Gas	0.00	0.12	397.3	0.02

The damages from emissions depend on both the location of the avoided emissions and the time of year. For this example, consider the damages from primary PM_{2.5}, SO₂, and NOx as given by EASIUR for two locations in the New York. These damages are shown in Table 5. Per unit of emissions, fine particulate matter is the most damaging of the three pollutants. In densely populated Queens County in New York City, damages per unit of particulate matter are much higher than damages in sparsely populated Franklin County. Moreover, pollution emitted in the two locations disperses to areas with much different populations. Emissions from a generator in Queens affect not only residents of Queens County, but other residents in New York City and Long Island. For these three pollutants, damages are higher in the spring and summer than in the winter or fall. In the EASIUR model, these different damages are largely a function of changes in pollution transport due to seasonal weather changes as well as seasonal differences in the rate at which primary pollutants become particulate matter.

The bottom of Table 5 shows the damages from emissions of CO₂.¹⁰⁸ As discussed above, damages from CO₂ do not depend on the time or location of the emissions. In this example, we have chosen the current Social Cost of Carbon minus a hypothetical \$5 price for permits in the Regional Greenhouse Gas Initiative.

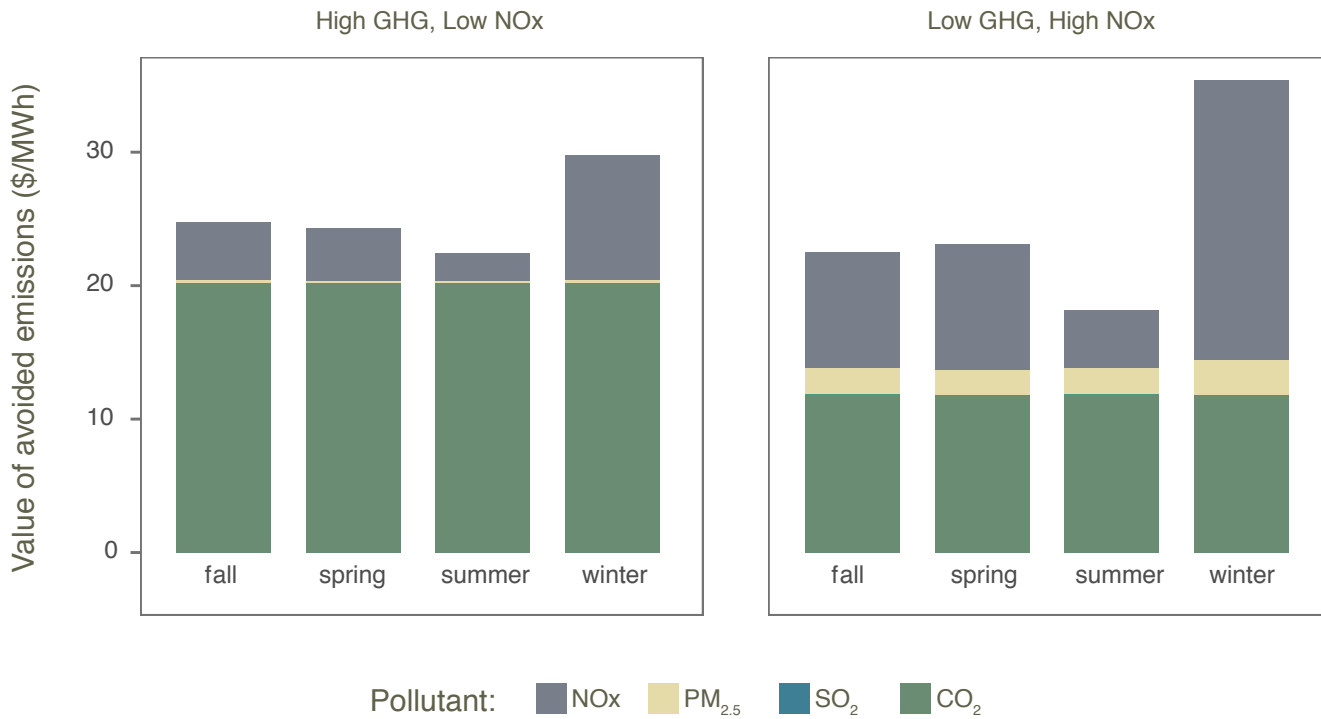
Table 5: Damage Per Unit of Emissions in Two Regions of New York¹⁰⁹

PM _{2.5} (\$/kg)				
Population	Winter	Spring	Summer	Fall
High	355	872	712	316
Low	107	48	50	80
NOx (\$/kg)				
Population	Winter	Spring	Summer	Fall
High	19	133	38	38
Low	21	4	2	4
SO ₂ (\$/kg)				
Population	Winter	Spring	Summer	Fall
High	12	102	71	21
Low	23	31	35	23
CO ₂ (\$/kg)				
Population	Winter	Spring	Summer	Fall
High	0.04			
Low	0.04			

Putting together the emissions rates from Table 4 and the damage per unit of emissions in Table 5, the environmental and health value for a zero-emitting DER can be calculated. For example, if a typical gas-powered generator was on the margin in the high-population, downstate region in the spring, then a zero-emitting DER would create roughly 5 cents of value per kWh of generation. In the lower-population upstate region, this value would be lower—around 2 cents per kWh. If higher-emitting fuels like oil were on the margin, then the value of DERs would be even higher. Previous publications show that oil heating and power generation lead to particularly high environmental and health damages in the New York City area.¹¹⁰ In contrast, if a zero-emitting resource like hydro power were on the margin, then a zero-emitting DER would create zero additional environmental value.

Figure 4 shows how the environmental and health value varies even among similar generators. The generator in the left panel is relatively inefficient—emitting a larger amount of carbon dioxide per unit of electricity generation than a typical plant in the state—but it is located in a sparsely populated area where NOx and PM_{2.5} emissions reach a smaller population. The generator in the right panel is relatively efficient, but its emissions of local air pollutants reach a larger population, increasing the value of avoiding those emissions.¹¹¹

Figure 4: Value of Avoided Emissions from Two Natural Gas Plants



The figure shows the value of avoided emissions for natural gas generators in New York state. The generator in the left panel emits more pollution per unit of generation than the typical gas generator in New York, but it is located in a sparsely populated area where NOx and PM2.5 emissions reach a smaller population. The generator in the right panel is located in a heavily populated area, so despite being relatively low emitting, its emissions of local air pollutants cause more health damage, increasing the value of avoiding those emissions.

Conclusion

Distributed energy resources can provide substantial value to a state by reducing the need for large-scale bulk system generation, thereby reducing pollutant emissions. The environmental and public health damage from this pollution is often imposed on vulnerable populations. As state utility regulators implement new compensation policies for these distributed resources, a key component of those policies should include payment for that value.

A straightforward five-step methodology, relying on existing or readily accessible tools, can be used to calculate the environmental and public health value of DERs. These tools can allow utility regulators to implement a compensation scheme that rewards DERs when and where they most enhance social welfare.

The methodology presented here is flexible enough to accommodate a variety of data and resource constraints. State regulators should weigh the tradeoffs between accuracy and administrability of different methods to calculating environmental and health value, pick the tools that are as accurate as possible given the tradeoffs, and then update their method when feasible.

Endnotes

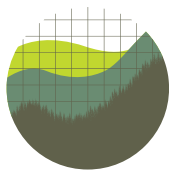
- ¹ Different states have implemented different definitions of DERs. See STAFF SUBCOMMITTEE ON RATE DESIGN, NAT'L ASS'N REGULATORY UTIL. COMM'RS, DISTRIBUTED ENERGY RESOURCES RATE DESIGN AND COMPENSATION 43 (2016), <https://pubs.naruc.org/pub/19FDF48B-AA57-5160-DBA1-BE2E9C2F7EA0>.
- ² *Id.* at 133-136, 142.
- ³ Richard L. Revesz & Burcin Unel, *Managing the Future of the Electricity Grid: Distributed Generation and Net Metering*, 41 HARV. ENVTL. L. REV. 43, 78-91 (2017), http://policyintegrity.org/files/publications/Managing_the_Future_of_the_Electricity_Grid.pdf [hereafter Revesz & Unel, *Distributed Generation*]; Richard L. Revesz & Burcin Unel, *Managing the Future of the Electricity Grid: Energy Storage and Greenhouse Gas Emissions*, 42 HARV. ENVTL. L. REV. (2018), http://harvardelr.com/wp-content/uploads/2018/03/revesz_unel.pdf [hereafter Revesz & Unel, *Energy Storage*].
- ⁴ In fact, every resource that avoids emissions—that is, any generating resource that emits less than the resource that would have generated instead—should be paid commensurate with the value of avoided health, climate, and economic damage. This report is specifically focused on DER because Public Utility Commissions in different states are presently focused on reforming the compensation structure of those resources. However, the methodology discussed could be applied more generally.
- ⁵ Revesz & Unel, *Distributed Generation*, *supra* note 3, at 101-108.
- ⁶ For more detail on the changing nature of federal-state divide over regulation of electricity, see Robert R. Nordhaus, *The Hazy "Bright Line": Defining Federal and State Regulation of Today's Electric Grid*, 36 ENERGY L.J. 203 (2015), http://felj.org/sites/default/files/docs/elj362/19-203-216-Nordhaus_FINAL%20%5B11.10%5D.pdf.
- ⁷ Revesz & Unel, *Distributed Generation*, *supra* note 3, at 85-86; Revesz & Unel, *Energy Storage*, *supra* note 3.
- ⁸ Revesz & Unel, *Distributed Generation*, *supra* note 3, at 85-86; Revesz & Unel, *Energy Storage*, *supra* note 3.
- ⁹ See DERIK BROEKHOFF ET AL., WORLD RESOURCES INSTITUTE, GUIDELINES FOR QUANTIFYING GHG REDUCTIONS FROM GRID-CONNECTED ELECTRICITY PROJECTS (2005), http://www.ghgprotocol.org/sites/default/files/ghgp/standards_supporting/Guidelines%20for%20Grid-Connected%20Electricity%20Projects.pdf.
- ¹⁰ To the extent that the counterfactual scenario identifies multiple generators that are offset by DERs, a generation-weighted average of displaced generators can be used in Steps 2-3.
- ¹¹ *Electric Generator Dispatch Depends on System Demand and the Relative Cost of Operation*, ENERGY INFO. AGENCY: TODAY IN ENERGY (Aug. 17, 2012), <https://www.eia.gov/todayinenergy/detail.php?id=7590>.
- ¹² See Broekhoff et al., *supra* note 9, at 63-65.
- ¹³ See ERIN BOYD, DEP'T OF ENERGY OFFICE OF ENERGY POLICY & SYS. ANALYSIS, OVERVIEW OF POWER SYSTEM MODELING 17-19 (2016), https://energy.gov/sites/prod/files/2016/02/f29/EPSCA_Power_Sector_Modeling_020416.pdf. The models particularly well suited to this type of analysis are "grid operation models" (otherwise known as "unit commitment and dispatch models" or "production cost models"). Models primarily designed for policy assessments, screening, and data analysis are not as well suited to this use. This includes EPA's AVOIDED EMISSIONS AND GENERATION TOOL (AVERT), a "high-level gross analysis" tool intended to estimate the emissions implications of new renewable capacity. *Id.* at 8. Nor are "capacity expansion models," such as IPM, NEMS, Haiku, ReEDS, and PLEXOS, which simulate generation and transmission investment decisions. *Id.* at 9, 11.
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- ²³ *Id.*
- ²⁴ Coal plants can install selective catalytic reduction technology that reduces NO_x pollution by over 80%, flue gas desulfurization (aka “scrubbers”) that can reduce SO₂ by up to 98%, and electrostatic precipitators and baghouse fabric filters that can drastically reduce PM emissions. EMANUELE MASSETTI ET AL., ORNL/SPR-2016/772, ENVIRONMENTAL QUALITY AND THE U.S. POWER SECTOR: AIR QUALITY, WATER QUALITY, LAND USE AND ENVIRONMENTAL JUSTICE 24-27 (2017), <https://energy.gov/sites/prod/files/2017/01/f34/Environment%20Baseline%20Vol.%202--Environmental%20Quality%20and%20the%20U.S.%20Power%20Sector--Air%20Quality%2C%20Water%20Quality%2C%20Land%20Use%2C%20and%20Environmental%20Justice.pdf>. Combustion Turbines can utilize water injection, dry controls (varying the amount of air needed for combustion), and selective catalytic reduction technology. AP-42, *supra* note 22, at 3.1-7. For combined cycle plants and stationary ICE, there are not pollution control technologies that are in wide use, beyond technologies and operational practices to improve plant efficiency.
- ²⁵ MASSETT, *supra* note 25, at 110-111
- ²⁶ Felipe R. Ponce Arrieta & Electro E. Silva Lora, *Influence of Ambient Temperature on Combined-Cycle Power-Plant Performance*, 80 APPLIED ENERGY 261 (2004).
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